

BULLETIN

OF THE

INTERNATIONAL RAILWAY CONGRESS

ASSOCIATION

(ENGLISH EDITION)

[624. (01)]

The present position as regards the question of dynamic influences on railway bridges,

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The German Review — *Die Bautechnik* — published in its 41st number of the 16 September 1927 an article by Professor Streletzky of Moscow on a new method of investigation into the dynamic effects in railway bridges. This method with a statement of the remarkable results obtained had already been published in a paper issued after the Railway Exhibition at Charlottenburg in 1924. In due course a quite detailed summary of this investigation of Mr. Streletzky was given in the *Bulletin of the Railway Congress* in its December 1926 number, page 1074.

In the following note we propose to make a broad though brief examination of the present position of the question of the dynamic effects in railway bridges, taking into account the particular points

of view of Mr. Streletzky and of the ordinary opinions most widely accepted at the present time in Europe and in America.

We would also point out that the International Union of Railways has drawn up a very wide programme of tests on this subject with the collaboration of the principal railway companies belonging to it.

I. — Introduction.

The question of the dynamic influences in railway bridges can be approached from two points of view :

1. Diagnosis of existing bridges from the point of view of the behaviour of their parts under loads at speed;
2. Determination of the proportions of the supplementary live loads to be taken into account in the calculation of the

structures so as to make allowance for the dynamic effects of loads at speed.

The essential difference between these two propositions is as follows :

The first provides for (according to Professor Streletzky's method) the fixing of average constants applying to the passage of complete loads.

The second has as its principal object the determination and the measurement of the local maxima.

The average figures expected will give information upon the organic state as a whole of the structure considered in its working with all its connections, that is to say, all the parts which help to make the strength of the whole unit.

The maximum local effects will shew if the individual limiting strength is exceeded at any point, and if any permanent local deflections are to be feared at any place. From the technical point of view these local maxima will indicate the maximum stresses to be expected in new projects and the margin of safety to be laid down.

As Mr. Streletzky points out, the field of investigation is the structure itself considered, either as the object of the tests or as a dynamometer.

The first sort of measurements taken on bridges by comparison with those from other bridges of the same kind or with those suggested by theory will give valuable information, especially of the *qualitative* kind, on the structure examined. In the second case — the structure being used as a dynamometer — if the measurements are to have any objective value and are to be comparable with those recorded on other structures, the test instrument must be calibrated against known standards, and the various factors

influencing the results must be ascertained and isolated.

Mr. Streletzky points out in this matter that the second problem is very complicated owing to the many different factors acting. If these determinations are to have any accurate technical value, it is then essential :

1. to work everywhere under comparable conditions;
2. to separate the principal factors in play;
3. to multiply the records taken so as to eliminate the effects of secondary influences.

As regards the measuring instruments, in view of the interest there is in tracing the influence lines of the factors being looked for, recording instruments naturally have much value. They should be easily operated and the records should be immediately visible; they should be strongly built, of average sensitivity and, as far as possible, have a period of vibration very widely separated from that of the structure itself so as not to affect the diagrams in a direction and in proportions that cannot be calculated.

Arriving at the dynamic co-efficient does not appear to be all that is required to determine the diagnosis of the structure. The value of this co-efficient obtained experimentally is doubtful. The tests shew in fact that there is some uncertainty on the subject of the true maximum ordinate of the dynamic diagram (vibration instruments). In addition, this co-efficient does not always give a clear picture of the dynamic effects because it does not deal with the effects produced by the permanent load (the exact reactions under permanent load being ignored — parts working statically at a reduced stress — variations in posi-

tion of the points on the diagram of the dynamic co-efficients).

Under these conditions, Mr. Streletzky suggests the calculation of other co-efficients, such as the co-efficient of area of the diagrams of influence and of that of deformations of the contours of the diagrams. In fact, the *preparation of the test influence diagrams* will make it possible to *apply simultaneously the two methods* without it being necessary to improvise particularly for either.

II. — Examination into the organic condition of a bridge.

Mr. Streletzky points out that the most efficient factor by which the organic condition of the bridge can be revealed would be the process of transforming in the structure the exterior energy supplied during the passage of moving loads into the energy of deformation. If the experimental diagrams allowed us to establish the proportion of the exterior energy converted into deformation energy and lost in the interior resistances of the structure, we should find ourselves in possession of a direct criterion of the state of the bridge.

Starting from this principle, it is desirable first of all to select a continuous diagram indicating the process of the deformation of the element or of the bridge, and then to compare it with the theoretical diagram drawn from the influence lines for a bridge truly elastic without interior losses of energy.

Mr. Streletzky proposes to substitute for the comparison of isolated ordinates from a test diagram and from a theoretical diagram that between the *influence surfaces obtained by experiment and by theory*.

The instrument registers during the passage of a train an influence line (test) of the element under observation. This

line delimits a surface which can be called experimental influence surface Ω_e .

We can draw the theoretical influence line and therefrom measure the surface Ω_t . The ratio $\frac{\Omega_e}{\Omega_t} = K_d$ determines a *co-efficient of surface* which gives an indication of the organic condition and of the strength of the bridge.

In principle, the co-efficient K_d should depend upon neither the speed nor the magnitude of the loads : *it then depends solely upon the structure*. Its superiority over an individual co-efficient — ratio of ordinates — lies in its general nature and in that its measurement is not subject to local errors of measurements.

According to the strict definition of this co-efficient K_d the speed should be totally eliminated when determining it, and it should be sufficient to arrive at it from the examination of a diagram at low speed.

If we maintained this argument, the true dynamic influence which shews itself by vibration — maxima and minima — on the diagram would not be recorded during the analysis of the experiment.

Mr. Streletzky returns to this and introduces the co-efficient γ which he calls the co-efficient of deformation of the contours of the influence diagrams

$$\gamma = \frac{Y_e}{Y_t} \times \frac{1}{K_d}$$

Y_e and Y_t are the theoretical and experimental maximum ordinates and K_d is the co-efficient of surface. *A priori*, this expression for γ appears rather confused : in developing the calculation we soon find that $\gamma = \frac{p_e}{p_t}$, p_e and p_t being the actual and theoretical equivalent uniform loads.

Without going into the details of an

extended and complicated analysis, it must be agreed that the co-efficient is clear and easy to determine.

It is probable that in many cases it may give a sure indication on the organic state of the structure. The values of reference *should be prepared by comparison with similar structures of good construction and satisfactory design.*

It would be useful if its use were generalised so that its meaning and ulterior use could be fixed without ambiguity.

It is, however, necessary to make some reserve. In principle, it is independent of the speed. Is it really so in fact? The question can only be answered by comparing the values of K_a calculated at reduced speed and at the maximum speed or at the critical running speed. The theoretical diagram is then rather a complicated one to draw. It is what Mr. Streltzky calls a staticodynamic diagram, the loads of the driving and coupled wheels being carefully determined, taking into account both the inertia forces of the parts having alternating movements and changes due to the action of the steam in the cylinders.

The signification of the co-efficient γ appears, on the other hand, less easily calculated. It will be interesting, none the less, to determine it in the cases dealt with experimentally in order to try to give it a precise meaning.

A third element can give interesting information as to the internal construction of a structure. This element is, on the one hand, the speed of propagation of the shocks and, on the other, the speed at which the amplitude of the vibrations decreases.

These measures can be made experimentally by shock (for example, at the middle of the bridge) by means of recording instruments started up at the same

moment and at the same speed indicating the amplitude and the speed of propagation of the vibrations.

This experiment by direct shock makes it also possible to determine an essential element, *the period of vibration of the structure.*

We must also call attention to a new element brought out by the Russian tests — that is to say, of the out-of-phase effect — delayed — to the maximum deformation in relation to that indicated by theory.

From the practical point of view, this out-of-phase effect indicates interior resistances of more or less magnitude in the transmission of the deformations, therefore of the organic condition of the bridge. It will give, in consequence, valuable indication on the state of the structure. Observations alone enable this sort of indication to be properly interpreted.

III. — Calculation of the dynamic effect.

The dynamic effect — impact — is a local dynamic increase expressed as a fraction of the static effect. This impact factor depends upon many factors: the factors including everything *are the organic construction and the condition of the structure, the type and condition of the line, the type and condition of the rolling stock, the operating speed.*

The multiplicity and complexity of the factors influencing the results are seen in the tests carried out so far by the dispersion and the very wide and often inexplicable differences in the results obtained. This mass of results can be compared to a mass of stars amongst which no precise line can be perceived.

Furthermore, there is very wide diver-

gence in the interpretation of the principal causes of impact, some people attributing to the state of the track the essential part, others, on the other hand, thinking the principal factor comes from the rolling stock and the speed.

When the tests have not been made after a definite plan, the causes of impact and the study of the results cannot be considered with any precision.

To forward the solution of the problem, it would be necessary to *systematise the tests* by *limiting and separating* as well as possible the *principal disturbing factors*. The end to attain would be to create a plan of certain points of observation relating to the essential causes properly determined: the subsequent observations could then complete the documentation by giving them a precision which is not entirely scientific, but will be at least technically certain.

When finally considering the principal causes of impact we think that in the test programmes they ought to be separated and their partial effects determined. Amongst the essential factors must be counted:

A. — Organic construction and condition of the structure.

The structure being considered as the dynamometer, it is essential it should be in a good state of upkeep.

The organic construction of the structures varies widely in the same country and in different countries. The part having most influence appears to be the flooring.

The influence of the flooring ought to be especially investigated:

1. with the line laid directly on the main girders or on stringers;
2. with the line laid continuously on ballast.

B. — Type and condition of the track.

In the case of a well maintained track laid with rails weighing about 50 kgr. per metre (100 lb. per yard) or roughly the heaviest rail actually in use in Europe at present, the factor having most influence is the *rail joint*. This point is considered by some engineers as the most important cause of impact. It is one of the factors it would be most interesting to solve. To this end, it would be well to organise tests with very well balanced motors:

on track with joints;

on track with continuous rails either welded or not.

In the first case it would also be necessary to distinguish between the *supported joint* and the *overhanging joint*.

The other inequalities of the track also have their effect: in a preliminary general investigation it would, however, be more rational to begin by studying the influence of the most important element, the others being eliminated by good maintenance.

It would also be desirable for the tests to be made *on a straight level line* to eliminate all the parasitic influences of the curves and gradients.

This line should have 50 kgr. per metre (100-lb. per yard) rails, or rails of about this weight. It is practically certain that, seeing the weight of the rail increases and with it the rigidity of the track, there should be, as regards the dynamic effects, a reduction of the « Hammerblow ». This is a subject for experiment if circumstances permit.

C. — Balancing of the locomotives and speed.

The influence of the balancing of the locomotives is closely allied to that of the

speed. The English and American engineers assign the greater part of the dynamic effects to the supplementary counter-balance weights used to balance horizontally the inertia forces of the reciprocating parts. In English this effect has been given the name « Hammerblow » which expresses in a rough-and-ready way the phenomenon.

In reality, the — hammerblow — does not occur suddenly : it is a periodic sinusoidal force which attains its maxima and minima when the counter-balance weight is down or upon the vertical centre line through the driving and coupled wheels. This periodic force sets up vibrations in the flooring. These vibrations only become cumulative and of importance when there is synchronism between the period of vibration of the bridge itself and the period of rotation of the wheel. The corresponding running speed is the *critical speed*.

It will be understood that the phenomenon would be closely defined if there were one wheel only moving over the bridge. Actually, the impulses succeed one another and may not be exactly synchronised for all the driving wheels of the same side of a locomotive : they shew themselves to have a certain and marked out-of-phase effect in relation to those on the other side of the engine — it is also necessary to take into account the action of the bogies and carrying wheels, etc. In fact, the English and American tests tend to prove beyond dispute that the critical speed exists and that it gives rise to the most important of the impact effects. This critical speed is not reached on small bridges and is only reached on bridges of considerable span.

It is also well not to forget that the action of the steam in the cylinders produces variations in the loads on the

wheels. This disturbing factor can, to some extent, mask the action of the counter-balance weights. It is then necessary, if we wish to bring out this latter influence clearly and to distinguish equally the steam action, to make parallel tests :

with regulator closed — without admitting steam;

with regulator open — with maximum admittance of steam.

The *influence of the speed* properly speaking is small if it is not closely connected with the action of the free counter-balance weights, steam action, flats on wheels, irregularities in the track, etc. It shews itself by the centrifugal forces produced by the deflection of the girders which increases the static loading. These increases are small and do not appreciably modify the stresses in the structures.

IV. — Conclusions.

We have quickly reviewed the points of view that can be held with regard to dynamic experiments on metal railway bridges and on the principal factors producing the dynamic loads. We have taken care to bring to notice the essential elements of the problem and have insisted upon the need for distinguishing them from one another and for creating *reference results* with which all subsequent experimental results can be compared.

From the results noted in Russia, it seems that the examination of the organic condition of the structures can be based upon comparisons between the *surfaces* of the experimental and theoretical diagrams. The calculation of the co-efficients of impact are based essentially on the measurement of the local maxima. These maxima can, moreover, be also interpreted in the sense of an examination

into the organic condition of the work. It is useful to note that these observations can be made at the same time and that the tests being made with recorders, the same elements can be used when applying the two methods proposed. These two methods, far from excluding one another, can be completed harmoniously and can

even help to make each other clear. We must then suggest their simultaneous adoption hoping that the Railway Companies will definitely embark on a series of systematic tests in order to shed a little light on this very obscure and controversial question of the dynamic influences in railway bridges.

The new steel rolling stock for express trains of the French Northern Railway Company,

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Figs. 1 to 19, pp. 725 to 749.

(*Revue générale des Chemins de fer.*)

The French Northern Railway has recently put into service the first vehicles of a series of 40 first and second class steel coaches specially designed for express trains.

These carriages which have side corridors and end doors, belong to the following classes :

1. First class carriages with 8 compartments :

A⁸ yfi (fig. 3).

2. First brakes (brake and 5 compartments) :

A⁵ D dyi (fig. 4).

3. Second class carriages with 9 compartments :

B⁹ yfi (fig. 5).

4. Second brakes (brake and 5 compartments) :

B⁵ D dyi (fig. 6).

The designs for this stock were made by the designing office of the Company's Chief Mechanical Engineer.

The orders for the construction of these 40 vehicles were placed with the « Ateliers de Construction du Nord de la France ».

In the present article we propose to set out :

A. — The principles on which the designs were based;

B. — The principal details of the equipment and decoration;

C. — The methods of manufacture and erection.

A. — General principles.

Mr. Bréwillé, the Chief Mechanical Engineer, considered that the structure of the new stock should provide every possible guarantee of safety for the passengers and of good behaviour in service that could be obtained by using metal even if new methods of construction had to be adopted.

The stock to be described in this article is not the first steel stock put into use on the Company's lines.

In 1923, the Company's shops at Hellemmes put in hand some coaches with side doors based on a general use of pressed work and of continuous welding.

From the investigations made and the experience gained at that time a special skill in these two classes of work has been developed as applied to the building of rolling stock.

This technique has now been perfected. The resulting processes have had their value proved by use and are described in chapter C. The definite knowledge that these methods can be applied industrially has made it possible for us to prepare the drawings for the new stock for express trains on the following lines :

I. — Body.

The body is built up from the following parts or groups of parts :

1. A strong shell of 4 mm. (0.158 inch) thick steel plate;
2. Transverse and longitudinal partitions;
3. Interior walls formed by the ceilings and the longitudinal panels.

We will not consider the ends for the moment : they will be dealt with specially later on.

SHELL. — The shell forms the fundamental element of the carriage. It should meet the following conditions :

a) Have the maximum strength against the principal and secondary stresses met with both in service and in case of collision.

In particular, all risk of telescoping must be considered as having been removed;

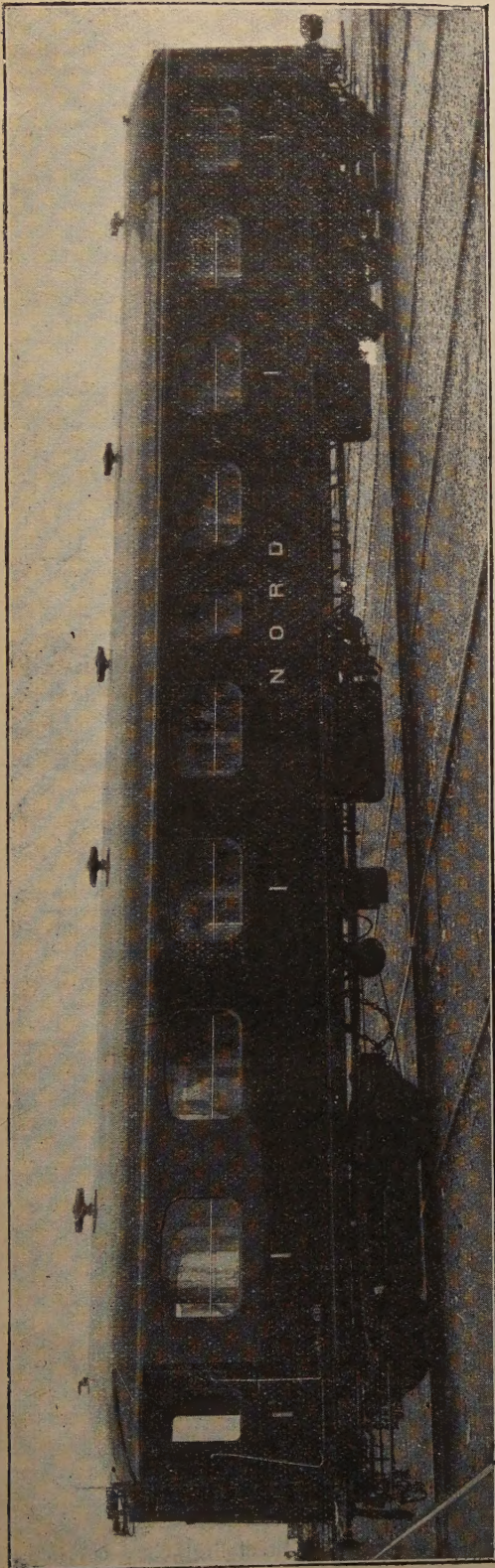
b) Remain indefinitely silent, that is to say, to require the parts to remain unalterably connected together;

c) Have the greatest stability at the highest speeds, that is to say, to possess itself the greatest period of oscillation during rolling, or the largest radius of gyration about the axis through the centres of oscillation of the bolsters of the bogies;

d) Offer the least resistance to the air.

The ideal construction of the shell to satisfy these differing requirements is that of a tube in a single piece in steel

Fig. 4. — First class carriage.



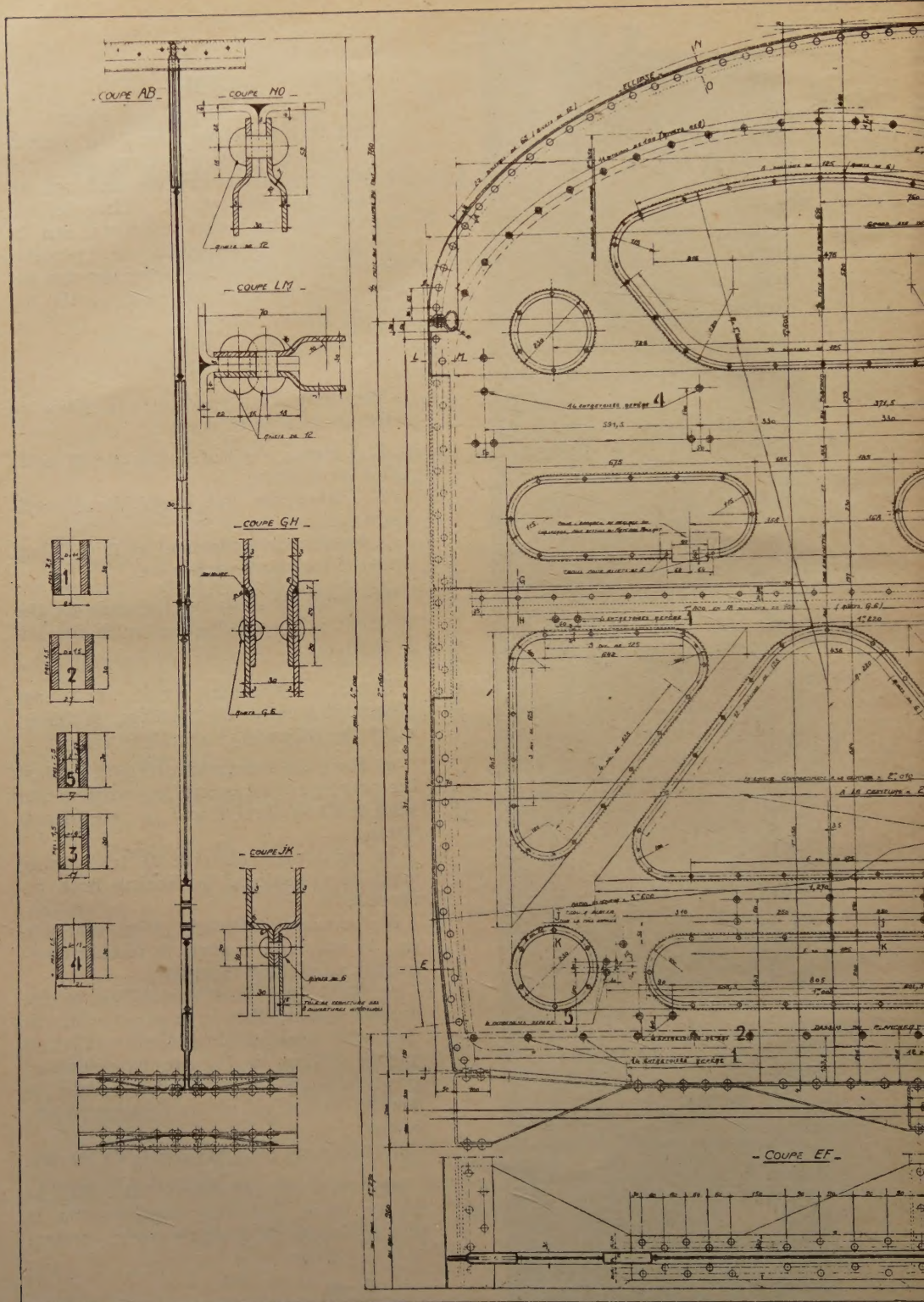


Fig. 2. — Steel first class carriage

plate of uniform thickness throughout without any joint, not only in the assembly of the constituent parts composing it, but also in the shape of these parts, provided with openings well rounded off at places free from bending and without exterior projections.

The two ends of the body will be connected to the shell with particular care. The vertical section of this shell only allows of arcs of curves tangential to each other, and its side walls also will be slightly turned under so that the whole will only have the flowing lines on which the aesthetical appearance of the vehicle at high speed is founded.

These general principles being thus defined, we can now give a brief description of the shell :

It is made up of three main parts (fig. 2):

1. The two exterior sides;
2. The roof.

The details of these three parts have the length of the corresponding compartments, and their four straight or curved edges are flanged over at right angles by simple bending or press work.

The flanges so obtained give them great intrinsic stiffness.

Sides. — The sides are made up by assembling panels as required by the class of vehicle which may be of five different types.

The openings therein have been obtained by cutting out and pressing the edges. These latter, turned over 90°, act as ribs. The stiffening obtained in this way has made it possible to extend the surface of the lights the maximum permitted by the interior arrangement.

Roof. — The roof is semi-elliptical having its parts arranged symmetrically in relation to the principal axis.

The only openings in it are those for ventilating the compartments and for filling the water tanks.

Under these conditions, the shell is reinforced on its inner side by a series of flanges orthogonal one to the other, as follows :

1. *The longitudinal flanges* formed by the adjacent turned over edges of the two symmetrical parts of the roof and the lateral walls. Their layout on any section of the shell is at right angles at their three top points to the section of the roof. Each of these flanges is held in place by a rolled section of special design of rail form.

2. *The transverse flanges* formed by the adjacent turned over edges of the straight sections of the shell. They are broken at three points to allow the rail section bars just mentioned to pass through.

There are as many flanges as there are transverse partitions between the two faces of which they are boxed in.

In addition to this interior system of flanges, there is a corresponding series of grooves on the exterior faces, these grooves being completely filled with metal by oxy-acetylene welding or arc-welding depending upon whether the work is done before or after erection of the shell.

It should be made clear that the two lateral walls and the roof are entirely finished before erection by welding; so much so that the only welds to be done on the completed shell are those required to complete the final joining together of the three parts. These are consequently the welds running along the two top edges of the lateral walls.

CROSS DIVISIONS. — These divisions are designed so as to ensure the rigidity of the shell as well as to make it difficult for the shell to be deformed in any direction.

They are built in the form of flat cases with lightening holes on each side, of

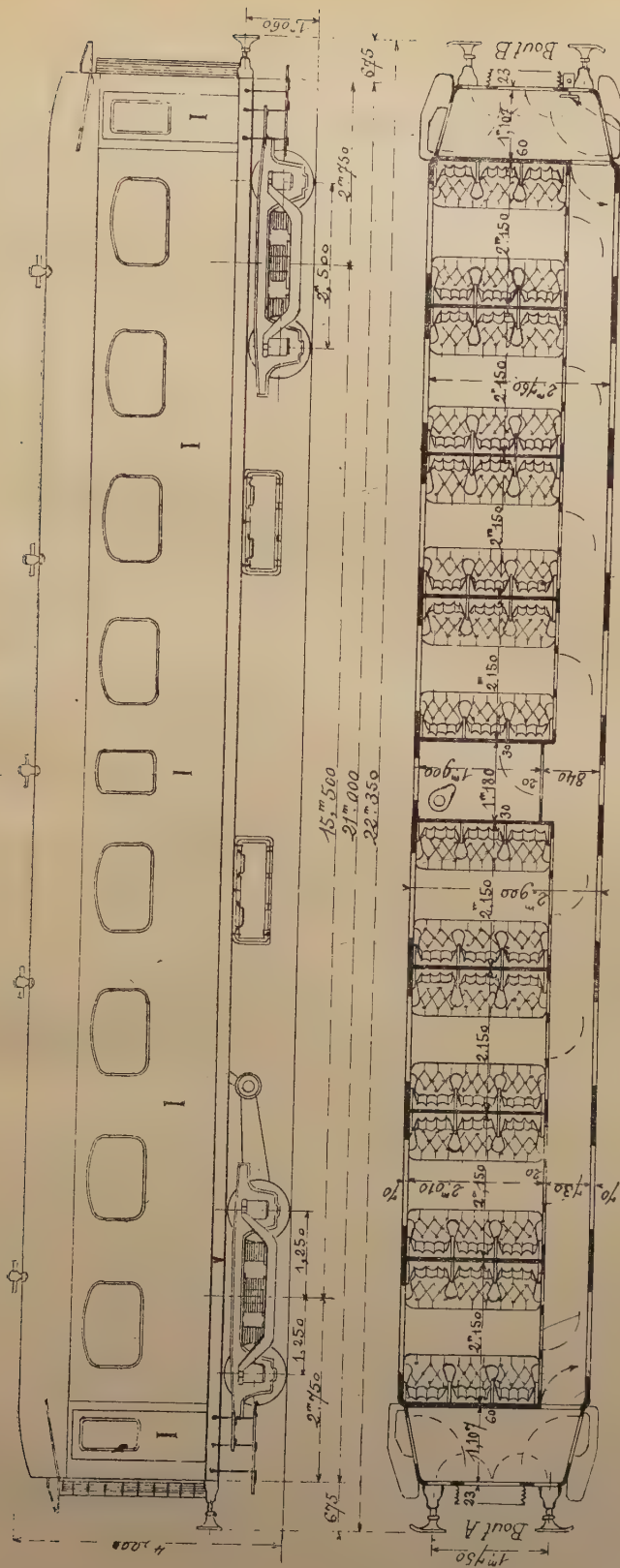


Fig. 3. — First class carriage.

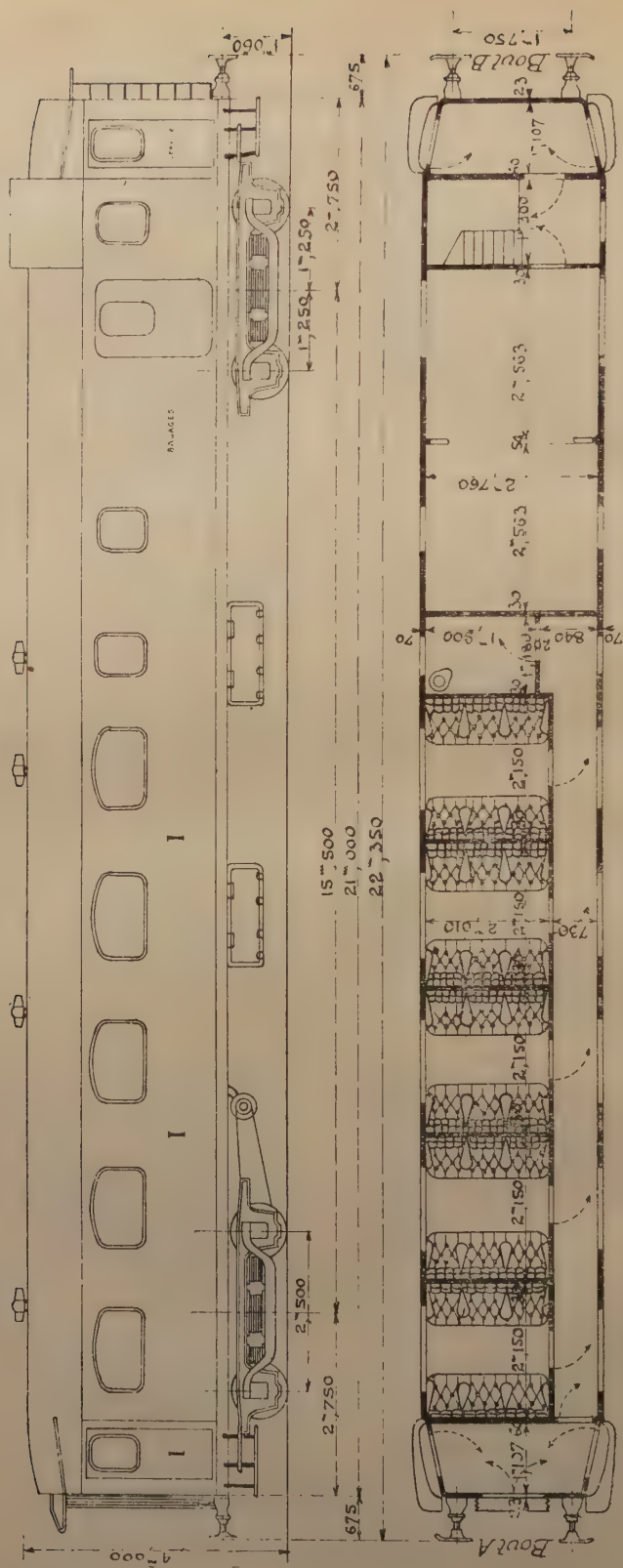


Fig. 4. — First class passenger brake.

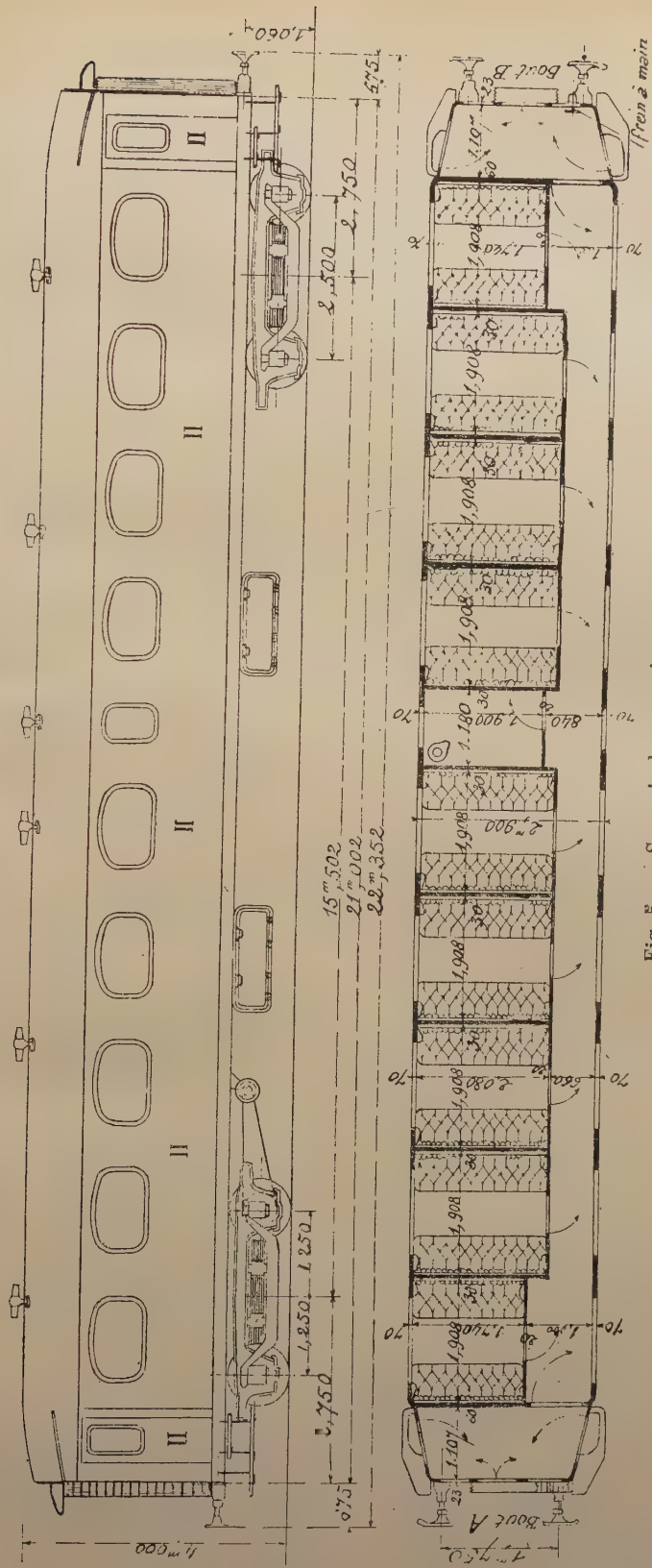


Fig. 5. — Second class carriage.

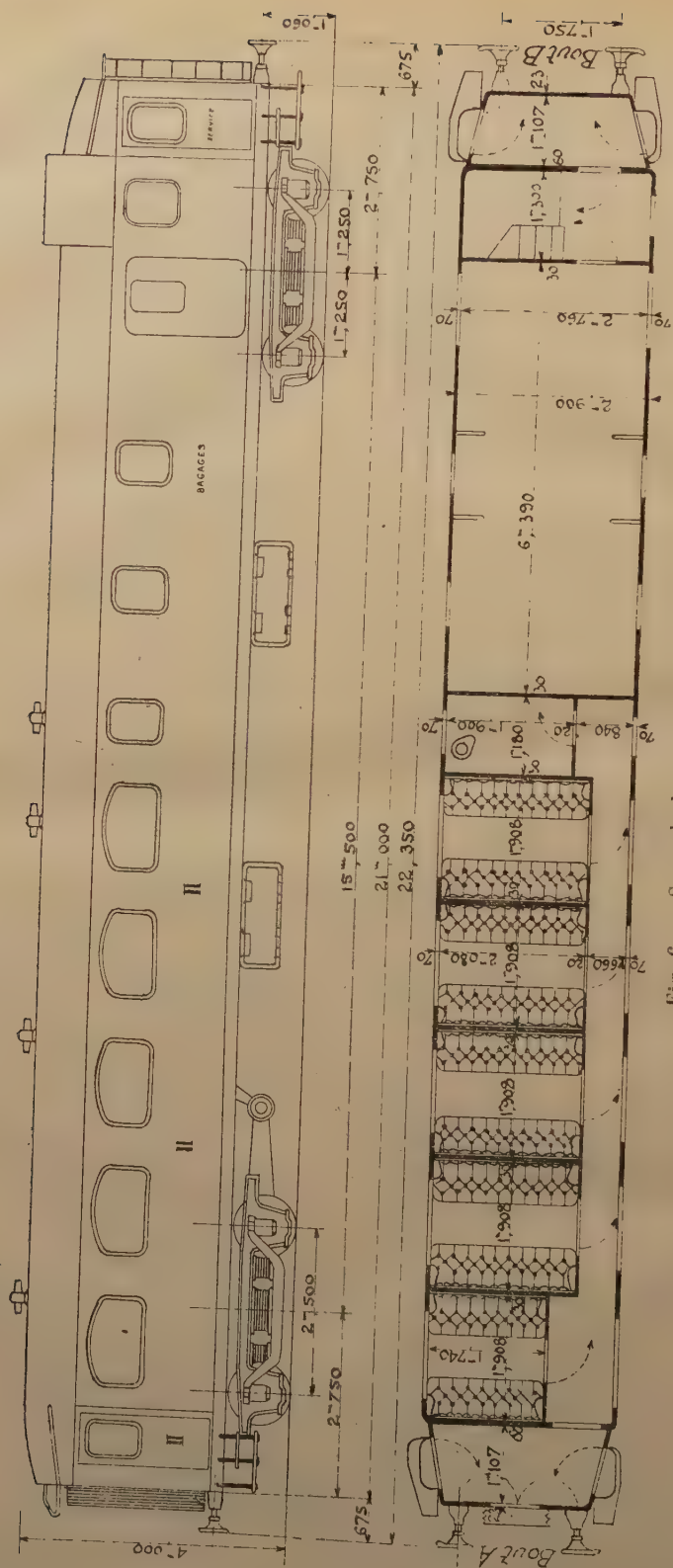


Fig. 6. — Second class passenger brake.

3 mm. (0.118 inch) plate, enclosing all round the transverse flanges we have just described.

These divisions have all been made as exactly alike as possible so as to reduce the tool equipment required.

The end partitions will be described separately from the intermediate.

The *end partitions* 60 mm. (2 3/8 inches) thick are of two types :

1. The partition separating the vestibule from the first compartment. The same design is used for the 1st and 2nd class carriages (fig. 7).

2. The partition between the vestibule and the luggage compartment in the passenger brakes.

The *intermediate divisions* are 30 mm. (1 3/16 inches) thick and have the following features (see fig. 2) :

The two sides are assembled by riveting round the hidden openings and by welding the visible flanged edges.

The weak part of these partitions being near to the longitudinal rail shaped member on the corridor side is strongly reinforced by a stiffening plate of two pieces of plate surrounding the flanged edges of the roof and welded edge to edge.

In the luggage compartment the partition is replaced by a ring shaped member (fig. 8).

LONGITUDINAL PARTITIONS. — These are formed of two flat cases 20 mm. (25/32 inch) thick, the two sides of which are of 1.5 mm. (0.059 inch) plate assembled by riveting and welding to internal stiffening plates : the vertical edges are turned over at 90° and held between the edges of the cross divisions. The openings made therein, namely, two window openings and a doorway, are fitted with window frames and doorways in Alpax.

FRAME (fig. 9). — This word is used to describe the whole assembly which, in reality, forms one piece with the shell,

consisting of the parts needed to properly join together the shell and the bogies, to serve in itself as support for the lateral walls at the places where the stresses developed by the bending of the body reach their maximum values, and to take the greater proportion of the traction and buffing stresses in service.

It is in principle made up of two soles in sheet steel 6 mm. (0.236 inch) thick bent into U shape of 200 × 100 mm. (7 7/8 × 3 15/16 inches) riveted to the lower flanged edges of the side panels and arc welded to these same edges after erection.


The bolsters and the drag boxes have been given a long bearing therein. These parts are in cast steel.

In this way, the whole unit of the two soles and the drag boxes may be considered as unlikely to become distorted in the horizontal plane.

For this reason it has not been cross braced. The usual pull and compression are applied to the drag boxes near their axis. The drag boxes are connected by two U bars in bent plate measuring 120 × 80 × 6 mm. (4 23/32 × 3 5/32 × 0.236 inches) designed to take and transmit these efforts without the drag boxes giving to any appreciable extent.

The intermediate cross divisions are rigidly attached to the frame. For this purpose, two continuous cross bearers are each fastened to the top flanges of the four U bars of the frame in line with each division.

The lower edges of the divisions previously flanged over are riveted to these bearers, to which fall, in consequence, the triple function of frame bracing, of strengthening ribs at right angles to the plane of the divisions and of gusset plates.

As for the end cross divisions, they are rigidly connected to the drag boxes all along their lower edges through a suitable bent plate member (.

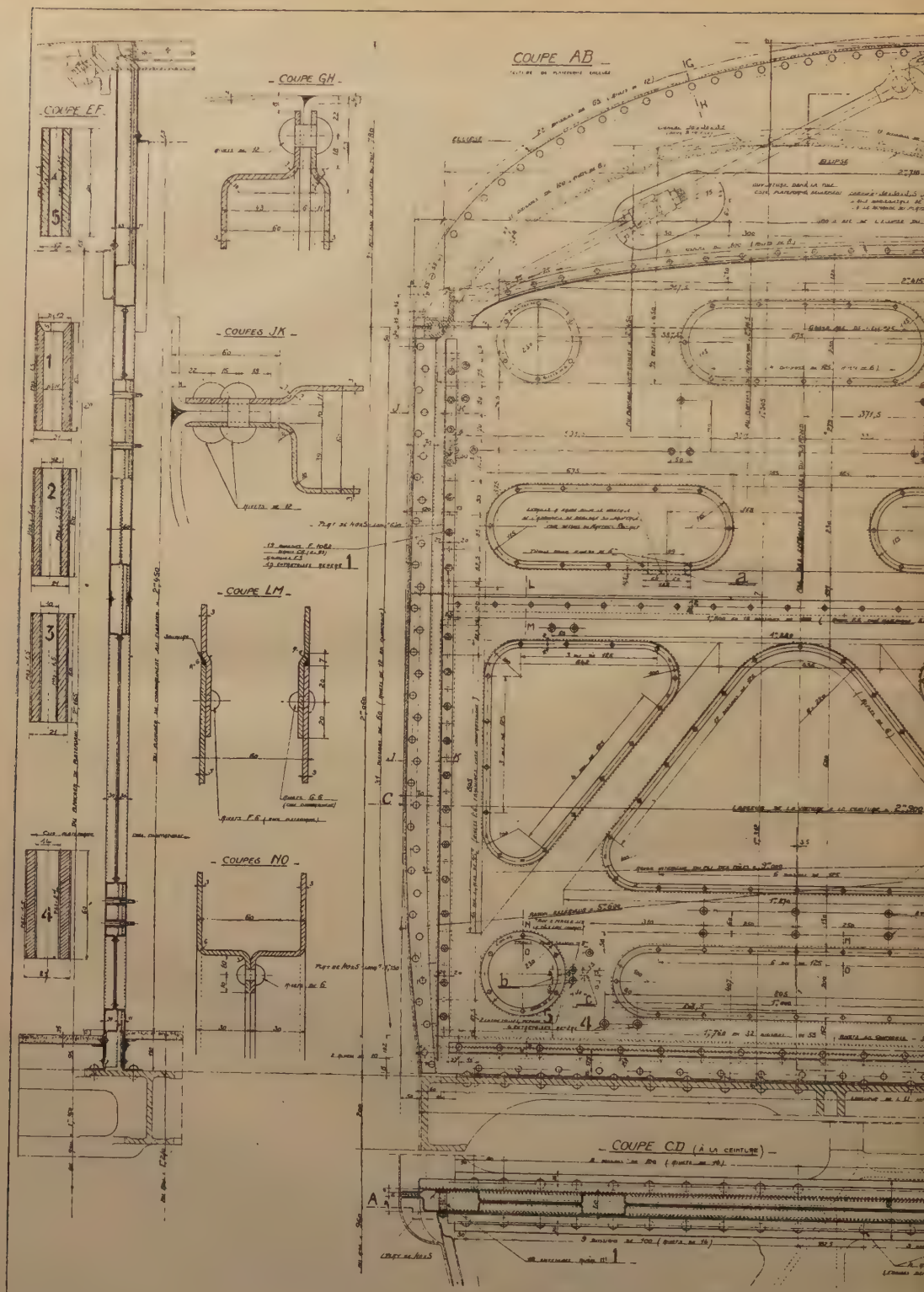


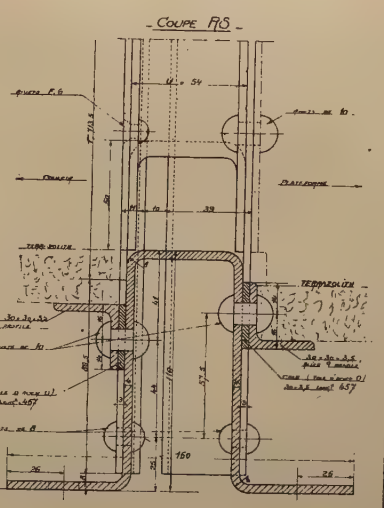
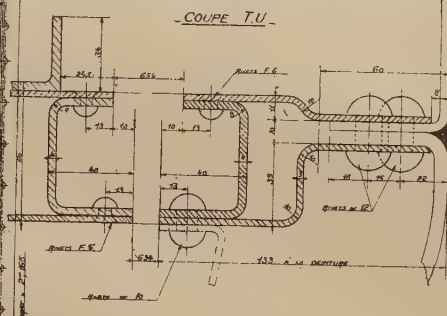
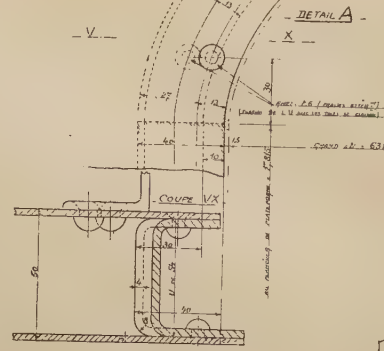
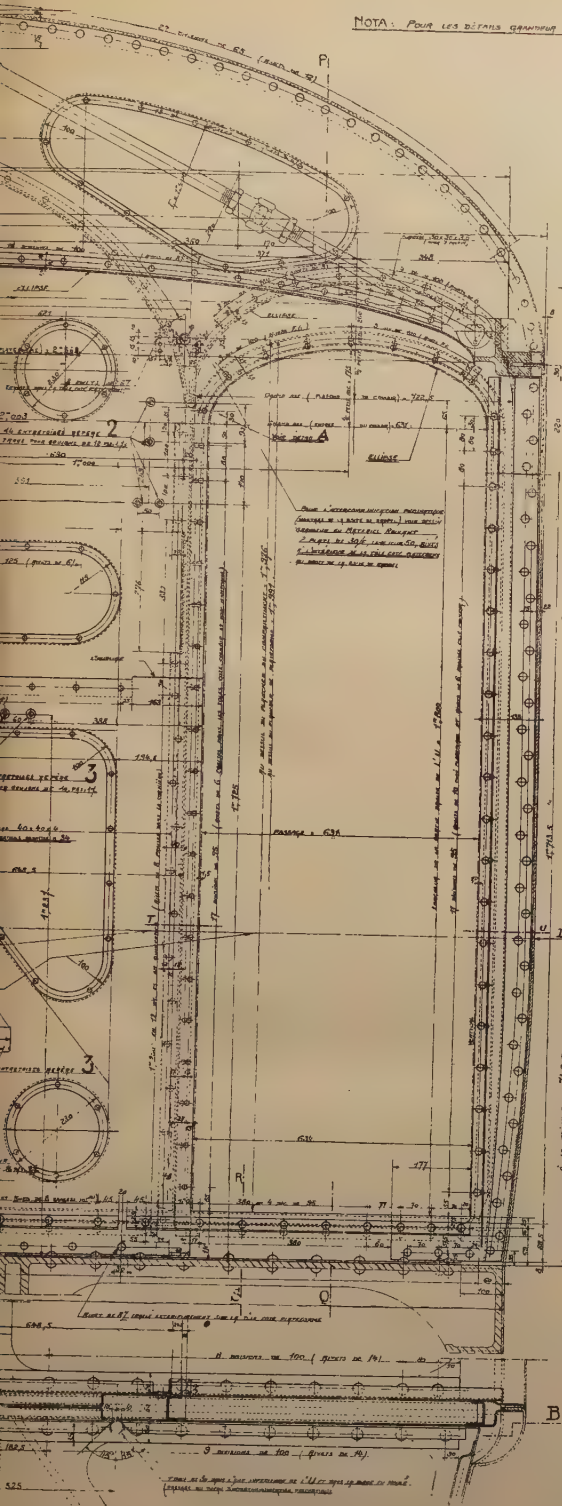
Fig. 7. — Steel first class carriage

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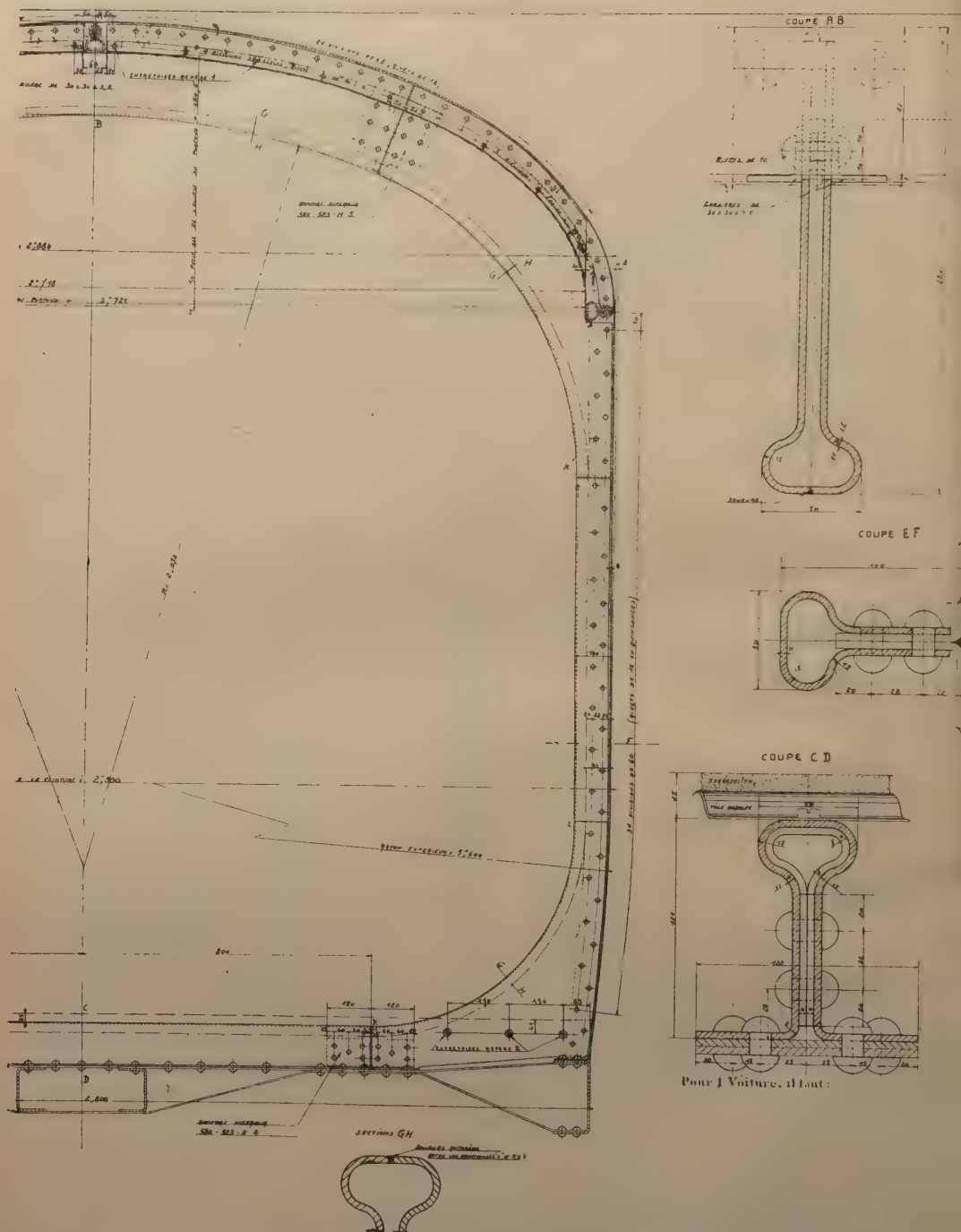


Fig. 8. — Ring in luggage compartment.

ENDS OF THE BODY (fig. 10). — The ends are the same for both classes of body, and are built up of the following parts :

1. An end in two or three panels according as the body end corresponds to the passenger compartments or to the brake end.

These panels are flat cases 30 mm. (1 3/16 inches) thick each provided with a light opening.

2. Three U bars in bent plate belonging to the same trapezium and having their lower flanges in the horizontal plane containing the axis of the lateral rail shaped members of the shell.

They are assembled together and with these members by means of steel castings.

3. Narrow panels framing the entrances to the vestibules and carrying the door pillars.

4. Uprights in 6 mm. (0.236 inch) plate designed to assure both the connection of the panels one with the other and with the shell, and the protection of the body along its vertical faces. They are riveted to the drag box along their lower end and to the cast steel parts of the trapezium at the top.

5. A roof in 2 mm. (0.079 inch) plate forming a quarter of an ellipse divided into two symmetrical parts with the edges flanged over.

6. A panel in 4 mm. (0.158 inch) plate fitted along the dividing line in the plane of the end face with a turned over edge riveted to the first corresponding U bar.

7. Two pieces of equal strength against bending used as supports to the vestibule face plates and rigidly connected to both the panels and to the sides of the U bars.

In order to increase their strength in the event of collision, the ends of the body have been provided with special fittings supported by the shell and including the following parts :

a) Two coned tubular members in

6 mm. (0.236 inch) plate connecting the end of the upper rail shape bar of the shell fitted for this purpose with a steel casting, to the top corners of the trapezium in the end.

The two ends of these coned tubes are articulated so as to give the three degrees of freedom needed and sufficient for the only stresses they have to take to be directed along their axes, no matter how much the end may become deformed.

b) Two vertical tie bars uniting the ends of these tubes to the drag box which they cross from one side to the other. They are intended to ensure the coned tubes remaining wholly effective in the event of the breaking or tearing away of the 6 mm. (0.236 inch) steel uprights already described, on the inside of which they are placed.

c) Two symmetrical oblique tie rods tying together the three cast steel parts fitted on the three ends of the rail shaped bars.

If to the special arrangement of the ends we keep in mind the three steel rail shaped bars, the trapezium in U, and the frame, we see that the carriage owes its resistance to shock to the triangulated construction so formed, and to the tubular shell. It will be seen that any unusual shocks, as well as those experienced in ordinary working, are taken and transmitted by longitudinal elements of great strength.

A safety arrangement of this kind could not be adopted without having subjected the coned tubes to a severe test for strength.

These coned tubes are made up of two truncated cones fitted and welded to a centre piece and each made up of a single sheet with the edges welded : a concentric tube 28×38 (1 1/8 \times 1 1/2 inches) connects their ends.

The terminal pieces screwed into the tube carry covers fitted and welded to the outside faces of the cone.

A coned tube of this design, tested under



Fig. 9. — View of a frame.



Fig. 10. — End of body fitted with special safety device.

loads checked by the dynamometer stood an axial compression of 45 tons without any damage other than a slight permanent deformation of one of its ends.

The thickness of the elliptical roof has been reduced to 2 mm. (0.079 inch) because its strength became negligible in view of that of the buffers.

The economy of weight so effected reduced the extra load due to the safety end arrangement by one half.

FLOORING. — The floor is built up of corrugated sheet steel panels carried on angle and U bars riveted to the divisions and the frame which they reinforce to an appreciable extent and is covered with terrazolite.

CEILINGS AND PANELING. — The ceilings are made of 1.5 mm. (0.059 inch) sheet forming elliptical ceilings with parallel axes in the compartments and in the corridor.

They are carried by steel angles riveted beforehand to the cross partitions and by the oak roof sticks reinforced by vertical steel flitch plates between the divisions.

The panels against the body side are carried by oak blocks held in place by knees welded to the walls.

These pieces of wood are so arranged as to prevent any circulation of air through the window openings into the space between the steel and the inside lining as the heat insulation obtained thereby is very important.

Wood has been selected for the roof sticks and blocks in preference to light alloys, as the latter were very costly at the time the construction of this stock was decided upon.

The ceilings and panels are then connected together and finished off by steel angles and plain joint covering strips.

Doors. — All doors other than those of the luggage compartment are hinged. They have been arranged so as to inter-

fere as little as possible with the corridor.

There are three different types of door :

1. *End doors* at the ends of the carriage. These doors are made up in the form of a flat box 30 mm. (1 3/16 inch) thick with the two faces of 1.5 mm. (0.059 inch) plate one of them alone, the outer, being flanged all round the light opening. Countersunk rivets hold the two sheets together along their edges and on the Alpax window frame.

2. *Inside doors* of three types. These are all made in the form of a hollow box 10 mm. (25/64 inch) thick in three parts:

a) Two sides in 1 mm. (0.0395 inch) plate with flanged edges. The edge of the light opening on the side of the door corresponding to the corridor is also flanged;

b) An internal frame work built up by autogenous welding from a number of small parts into a single unit to which the two face plates are secured. These three parts are assembled by electric spot welding and completed all round the edges of the face plates by welding with the flame.

Luggage compartment doors. — These doors roll on a guide on a level with the top of the floor : they slide into the shell when open.

They are made of one piece of 4 mm. (0.158 inch) plate with the edges flanged over.

In order to suppress vibrations, we have fitted them up specially. At each of the upper corners of the door a frame with two wheels revolving about a vertical pin is fitted. The wheels roll on the inside faces of a single U section guide against which they are held by a torsion spring.

Two small ramps riveted on the inside face of the guide brake the door towards the end of its movement, should any

sudden jerk in the train cause it to close too quickly.

Doorway framing. — With the exception of the lower edge which is a brass sill piece, the framing of all the doorways is made of three pieces of Alpax fitted in between the two faces of the partition concerned.

The door pillars of the entrance doors into the corridor are held in place by screws.

The vertical pillars of the doors and the two sides of the longitudinal partitions are assembled by a special machined countersunk headed rivet drilled and tapped internally. The screws fastening the joint covering strips and the decorative panels are screwed into these tapped holes and consequently can be taken out and put back very many times before the inside threads become damaged (fig. 11).

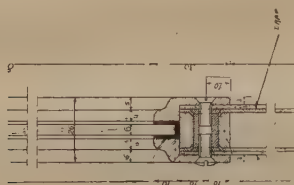


Fig. 11.

Section through a light in a corridor partition.

Finally all the door pillars excepting only those at the ends of the corridors are fitted with rubber strips held in dove-tailed slots in order to make the closing of the doors perfectly silent.

Framing of the corridor partition lights.

— The lights are fitted with Alpax frames placed between the two faces of the cross divisions and fastened thereto by countersunk rivets with an internally screwed hole of the same design as those described above. The glass is held in place by two Alpax frames the screws holding which are screwed into the rivets.

II. — Bogies.

The bogies are of the « Pennsylvania » type (fig. 12). The frame is a single piece steel casting. Each frame before delivery has passed a severe statical test by requiring it to carry in the same way as in ordinary service but whilst stationary and for 24 hours a weight of 52 tons.

No permanent set was noticed. The deflection varied from 0.5 to 1.5 mm. (0.0195 to 0.059 inch).

The axles are fitted with « Isothermos » axleboxes.

Finally, in order to make the brake gear silent, we have adopted a parallelogram arrangement of parts which prevents any part of the gear from touching the bogie.

The body is carried by the bogie by means of two spherical bronze centre bearings, lubricated under pressure from a distance by means of a Stauffer grease cap using grease placed under the sills.

The flexibility of each group of elliptical springs is 12 mm. (15/32 inch) per ton.

That of each of the four groups of coil springs is 16.7 mm. (21/32 inch) per ton.

The weight of a bogie in running order is 6 500 kgr. (14 330 lb.).

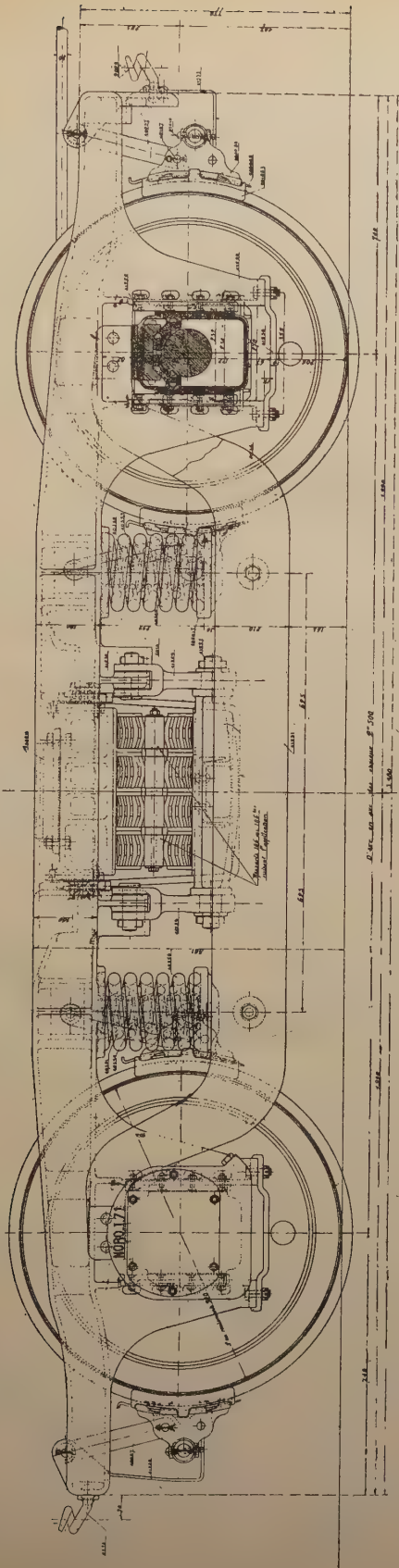
B. — Equipment and fittings.

LIGHTING. — The electric light is of the Brown-Boveri self-contained system consisting of a dynamo carried on the frame, a battery of accumulators and a Mauron system regulator.

All the light fittings have « Holophane » fittings which diffuse the light uniformly about their vertical axis in the compartment and parallel to the axis of the coach in the corridor.

In the first class, each compartment is lighted by a two-arm fitting in gilded bronze, each arm carrying a 25-candle power gas-filled bulb and shade. A night light of 8-candle power is fitted between the two arms of the fitting.

Elevation.



Coupe longitudinale

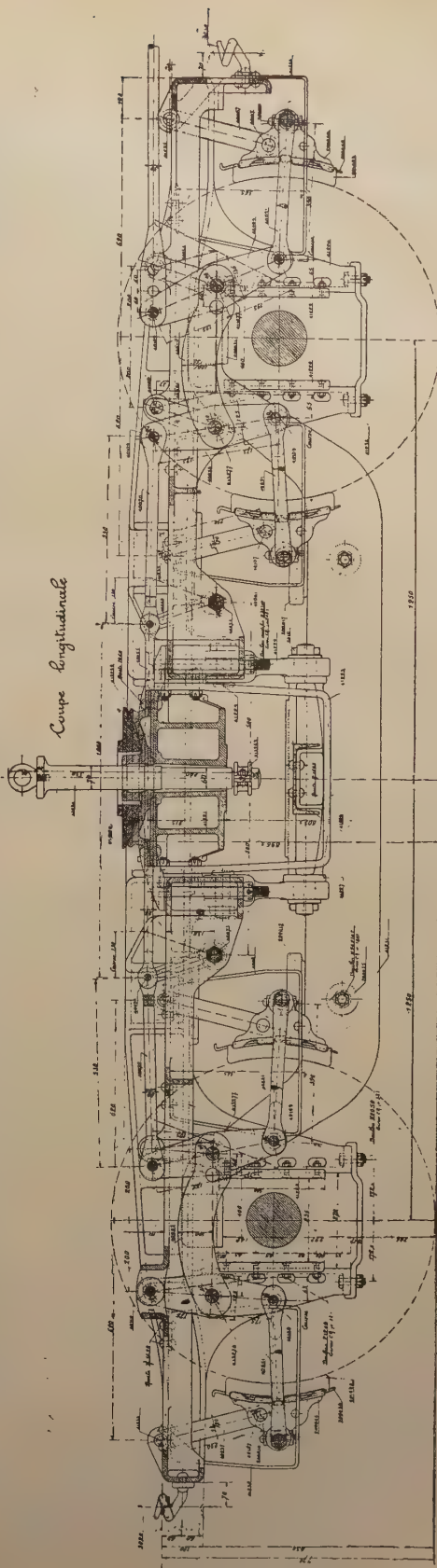


Fig. 12. — Bogie.

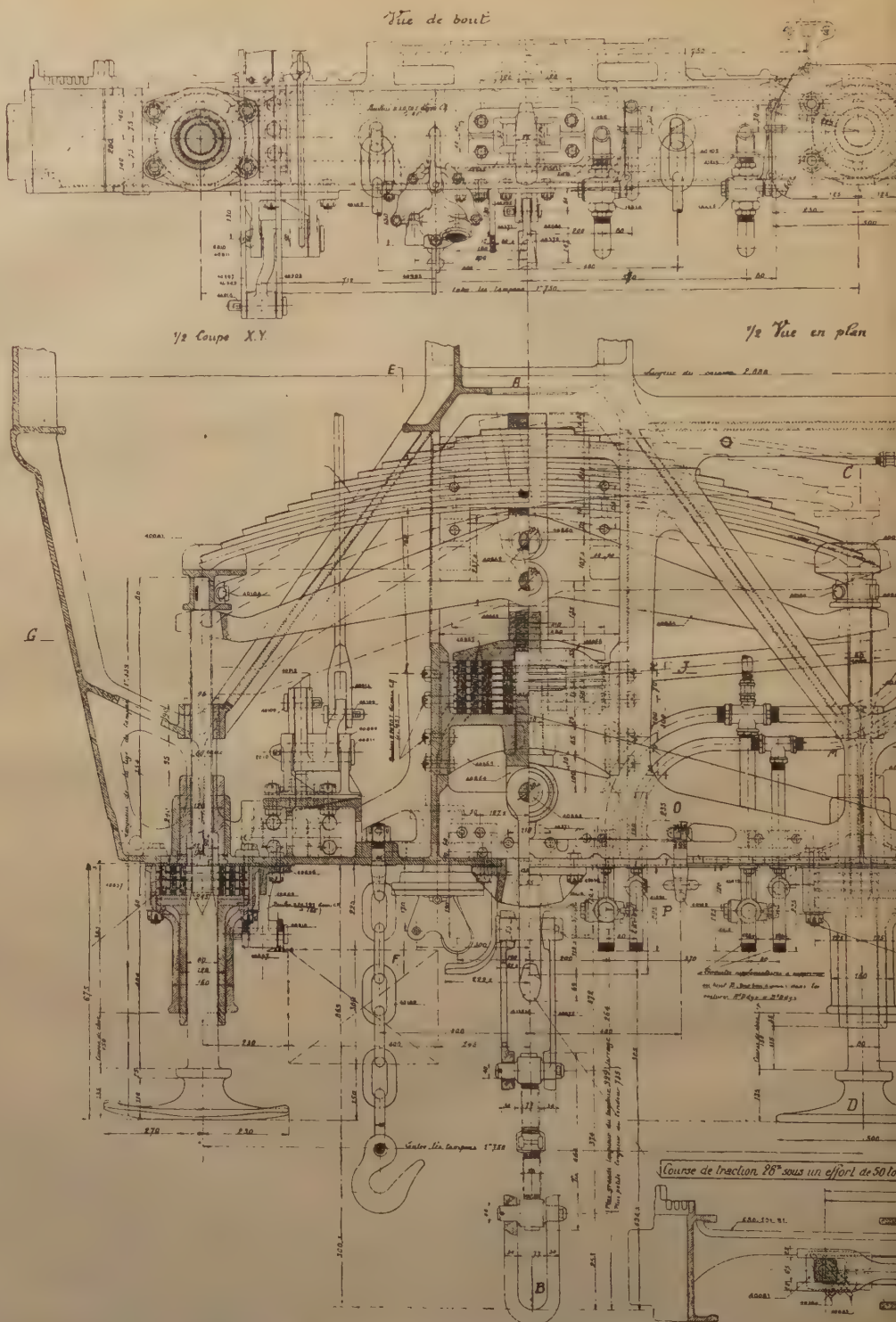


Fig. 13. — Steel carriage for e

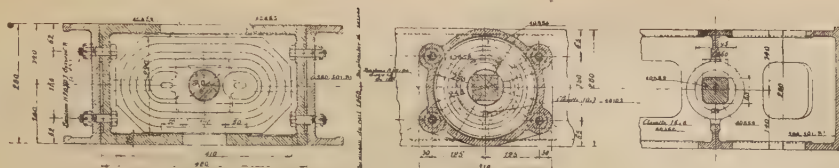
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Coups suivant

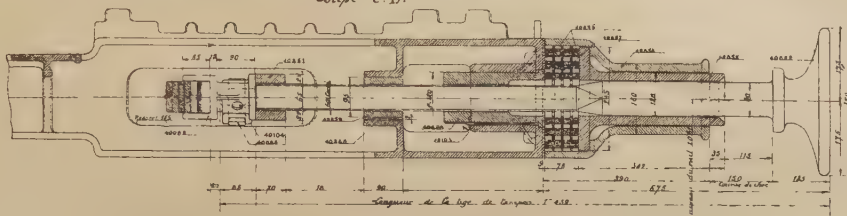
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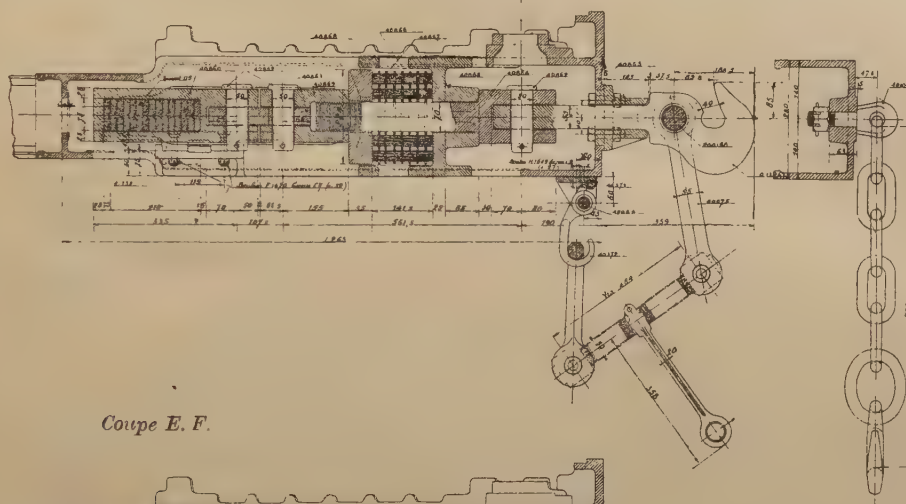
M. N.



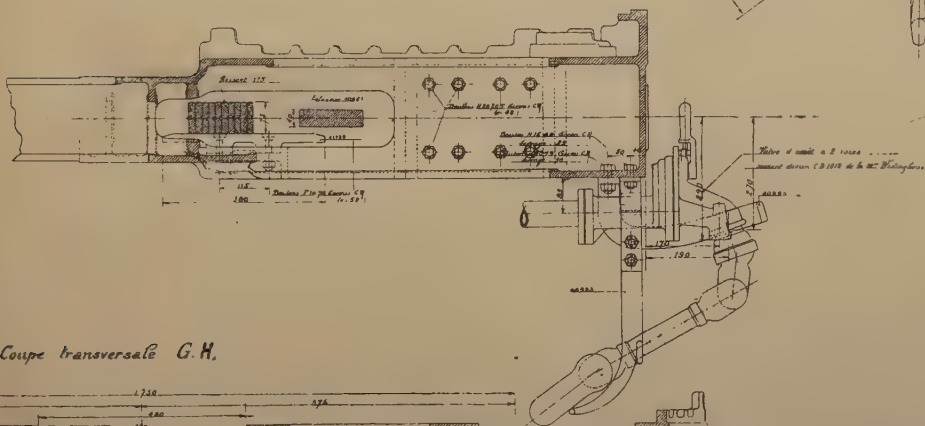
Coupe C. D.



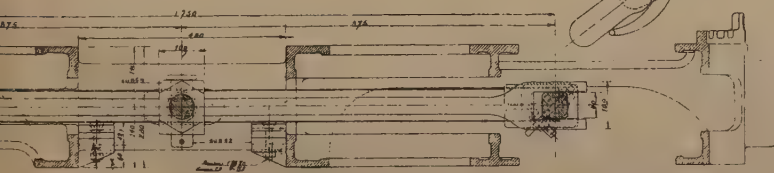
Coupe A. B.



Coupe E. F.



Coupe transversale G. H.



ns. — Drag box and draw gear.

In the second class, these three bulbs are fitted in an aluminium ceiling fitting.

HEATING. — The heating is on the Westinghouse system with thermostatic control. The main pipe 54/50 (2 1/8 × 1 31/32 inches) is fitted with metal coupling pipes.

Each compartment has two radiators, one under each seat, adjustable by means of suitable gear, and also a foot warmer.

The vestibule and corridors are heated by independent radiators.

The temperature of the radiators is set to 90° C. (194° F.) and that of the foot warmer to 60° C. (140° F.).

BRAKE. — All the vehicles are fitted with the rapid acting Westinghouse brake, the Henry moderable brake, and hand brake.

The internal diameter of the cylinder is 355 mm. (14 inches); the total leverage between the air cylinder and the blocks is 11.

The wheels can be removed without any part of the brake gear having to come down.

The brake shoes are of the standard U₂ type with separate backs.

An automatic brake adjuster S. A. B. system is fitted on the brake pull rod; it has been designed so that the shoes and tyres can be worn to their extreme limit without any adjustment of the brake gear being required.

PASSENGER COMMUNICATION. — The usual pattern with lever operated alarm signal and indicating box is fitted.

The guard's compartment and the vestibule of the brake van are each fitted with a 3/4 inch alarm cock.

A cord connects the cock of this vestibule to the driver's cab so that in case of need the driver also can open it.

COUPLINGS (fig. 13). — The couplings, based on the classic design of Chevalier & Rey, have been got out so as to ensure permanent contact between the buffers

of the carriages coupled together as well as the transmission of the normal pull and compression stresses through the centre line of the frame.

The draw bar pull is taken on a Spencer's India rubber spring; the buffers act on a laminated spring.

The buffer casings are fitted with Spencer's India rubber springs, which consist of concentric rubber rings on steel plates with steel separating plates. The plates carrying the rubber rings have openings in them which act as keys for the rubber which is formed on both sides thereof.

The use of these springs is general in England.

It will be seen that, thanks to these rubber springs in the buffer cases, the shocks, no matter how violent, are always transmitted through shock absorbing parts.

The elastic deflection of the centre bar is shewn on the diagram below (fig. 14).

INTERIOR FINISHING AND DECORATION. — The insulation by layers of cork and of still air, and the absence of any riveting, has enabled us to avoid any interior wood work in the compartments.

The good appearance of the interior has been obtained by the sobriety and harmony of the lines (fig. 15).

Thanks to the connection of the ceilings to the upright faces and the continuity of contour, the same harmonious appearance has been achieved between the outside lines of the carriages as between those inside.

The seats are trimmed with cloth in the compartments, and in imitation leather in the corridors and vestibule ends (fig. 16).

The first class compartments are decorated with ornamental panels mounted above the backs, provided with an oval mirror at the centre, framed in faience of different colours according to the compartment.

The seats are framed in and supported at the two ends and have loose cushions

The first class are upholstered in grey Bedford cord and the seconds in brown faced cloth.

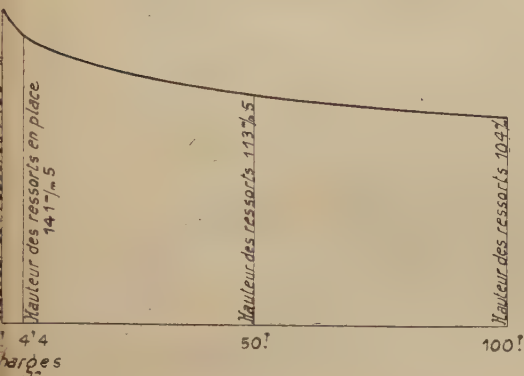


Fig. 14. — Deflections of the draw bar tail pin.

Explanation of French terms: Hauteur des ressorts 155 mm. = Height of springs: 155 mm. (6 1/8 inches). — Hauteur des ressorts en place 141 mm. 5 = Height of springs in position: 141.5 mm. (5 9/16 inches). — Charges = Loads.

The gilded fittings in the first class harmonise in tone with the blue and old gold of the carpets, curtains and laces.

The coldness of the white fittings in the second class is softened by the soft brown shade of the trimming materials.

The cross divisions are finished above the net racks with embossed panels with reeded edges.

The lights have a width of 1.300 metres (4 ft. 3 3/16 in.).

A number of the corridor lights are fixed: the remainder have drop lights fitted with Hera lifts.

Any water getting in between the inner and outer wall is led away under the frame. The two layers of cork applied between the inner and outer wall are 10 mm. (25/64 inch) thick.

TOILETS. — In order to facilitate clean-

ing, the toilet has been placed at the centre of the coach. With a view to respecting one of the fundamental principles of the design *i. e.*, the absence of any important opening in the roof, we have designed a new method of fitting and securing the water tank (fig. 17):

1. The two twin tanks, each containing 400 litres (88 Imperial gallons) are each taken in through the toilet door. A tackle is hooked on to the pin A. The chain is fastened in the eye on the frame of the tank which is then hoisted up until the clips G hook on to the auxiliary tube T;

2. With the tackle alone, the tank is turned about the tube T until the corresponding edge rests on the tube T₁. Continuing the lift, the tank rotates about the tube T₁;

3. When the tank is high enough, the tube T₂ is put in place. The tank is then lowered;

4. The two tanks now in position are finally fastened in place by locking wedges and two bolts.

The water to be heated circulates round a steam coil in a chamber arranged in one of the two tanks.

This coil is continued through the cold water so as to prevent it from freezing.

The wash basin, the shelf and the toilet paper holder are in porcelain.

The hopper is the Porcher type with flap and water flush pneumatically controlled by a pedal.

The walls are lined with plates painted over an undercoat of vitreous enamel. The floor is covered with tiles on a cement foundation.

C. — Methods of construction.

The Company's workshops at Hellemmes were given orders in 1923 to build, as a trial, a rake of 12 steel coaches with side doors for fast trains having the sides in one piece.

The difficult problem was solved thanks to the skill of the staff specialis-



Fig. 15. — View of a first class compartment taken from outside the carriage.



Fig. 16. — Corridor of first class carriage.

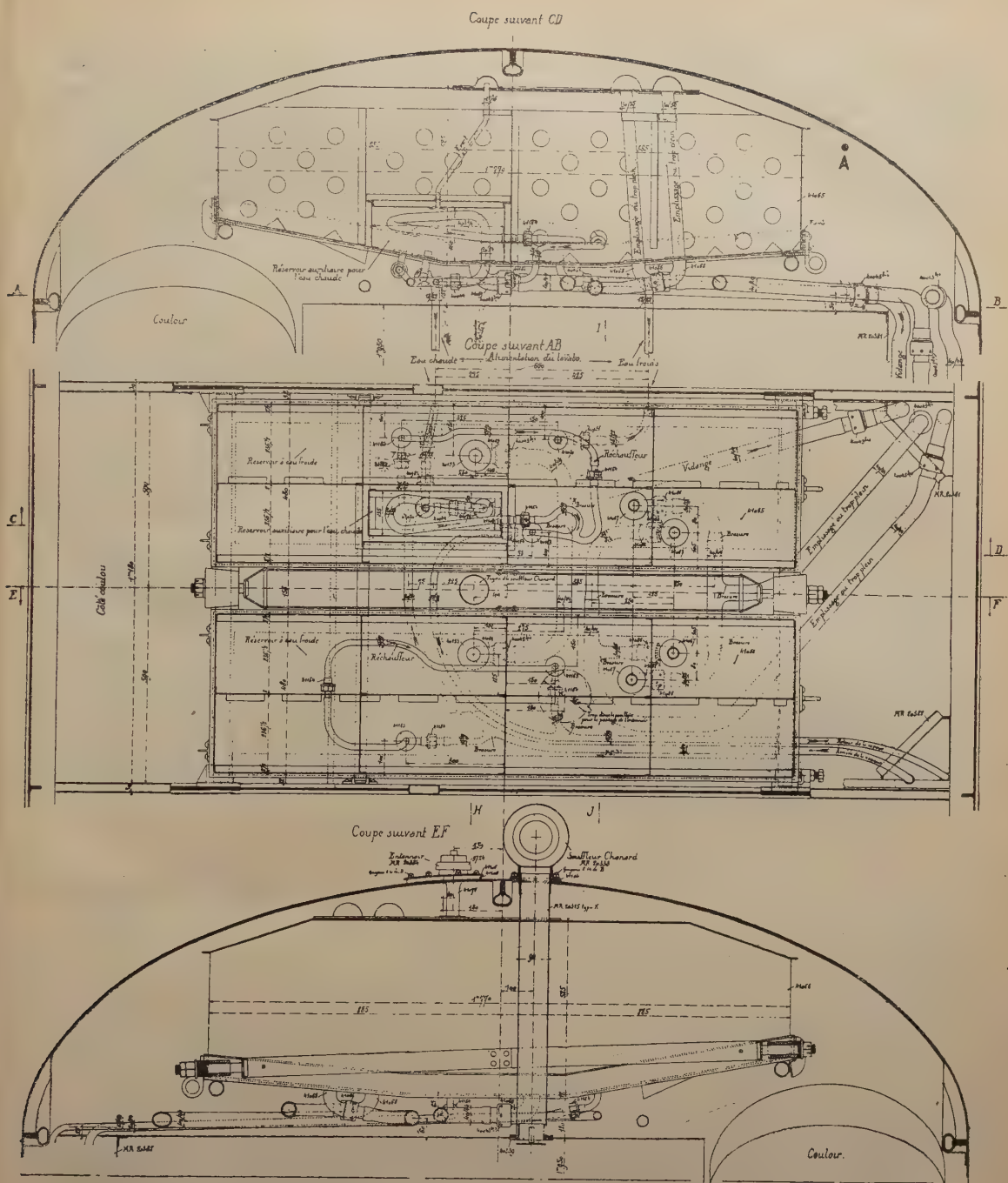


Fig. 17. — Fitting of the water tanks in the toilet.



Fig. 18 — General view of the erection stands shewing the different phases of the construction of the carriages and of the making up of the body sides and roofs.

ing on welding and press work. The practical methods having been learnt, the design and construction of stock for express trains were undertaken in all confidence, both as regards the practicability of building them and as regards the cost of construction.

I. — MANUFACTURE OF THE BODY SIDES AND ROOF. — The panels to be welded are put together, three at a time, on levelling tables of heavy plate (fig. 18).

Location points are marked in these panels near the edges in contact.

1. The bottom of the groove formed by the turned-over edges of two adjacent panels are first of all welded electrically so as to form a base for the subsequent oxy-acetylene welding.

This precaution was found to be essential: it makes it possible to avoid the twisting inevitable with the flame if this latter penetrates between the plates.

2. Flame welding is then resorted to, consecutive lengths of 10 cm. ($3 \frac{15}{16}$ inches) being welded at a time. As soon as the weld is finished, it is well ham-

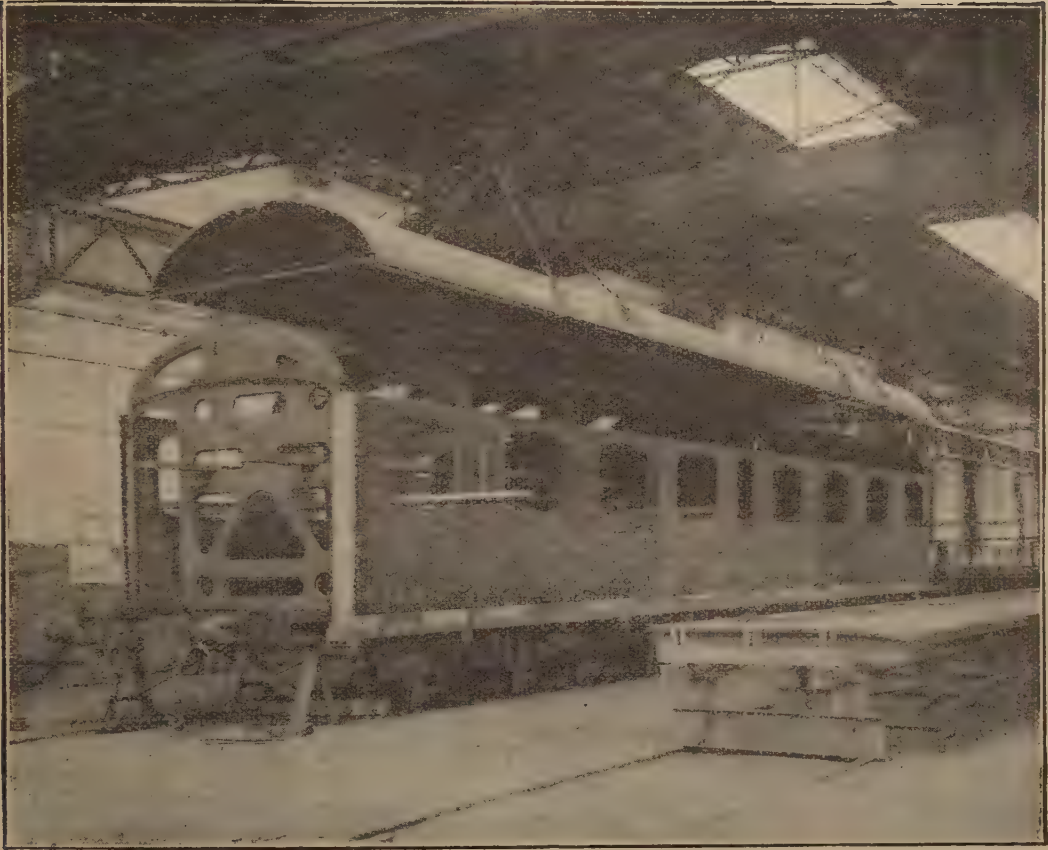


Fig. 19. — Placing the roof into position.

mered, the blows of the hammer increasing gradually.

The object of this operation is to counteract the retraction during cooling off.

3. The joint is levelled off with a set.

The work is stopped when the location points are at the same distance apart as when marked off.

Panels formed of several of the original small panels are then in their turn assembled together in the same way so as to form a single side wall or one half roof.

This method is of such accuracy that

the total error on the total length of one side, namely 19 m. (62 ft. 4 in.) is about 1 mm. (0.0395 inch).

The side so formed undergoes before erection the final operations for checking its dimension and for levelling it by the very convenient method known as the « shrinking heat ».

This method consists in heating intensely by the flame or electrically, suitably selected parts of the area out of shape.

The metal gathers back, as it were, and, if need be, is helped by light hammering: during cooling, which may be helped by

a jet of compressed air, the retraction definitely levels the area so treated.

II. — MANUFACTURE OF PRESSED STEEL PARTS. — The shops at Blanc-Misseron, not being fitted with the special machinery required, obtained the more important pressed parts from an outside firm specialising on this work. The rolled sections of the frame, the panels of the sides, of the roof and the rail shaped bars were supplied by the « Société des Forges de Recquignies ».

The side panels were flanged cold.

The said rail shaped bars were made by hot drawing a bar roughed into U shape with the end forged to the finished section : the inside section was obtained by stamping.

The details of the cross divisions were supplied by the « Etablissements Arbel ». After being properly annealed, they were pressed and cut out at the same time by means of profile cutters fitted with hardened steel blades.

CASTINGS. — The large steel castings, drag boxes, bogie bolsters, bogie frames were supplied cast and machined by the « Aciéries de Haine-Saint-Pierre et Lesquin ».

The parts in Alpax were supplied by the « Etablissements Montupet ».

MANUFACTURE OF DETAIL PARTS. — The Blanc-Misseron shops have made full use of modern methods of making parts by means of jigs for gauging, machining and drilling, and thereby avoiding all marking off, and ensuring interchangeability.

ERECTION OF THE COACHES. — The erection stands placed at the centre of the assembling benches are made up of carefully levelled trestles laterally connected by strips of heavy plate which serve as jigs for locating the frame (fig. 19).

The finished frame having been put into position, the erection of the body takes place in the following order :

1. Cross divisions;

2. Longitudinal partitions ;
3. Body along side corridor;
4. Opposite body side.

These two latter parts are temporarily bolted up so that the top edges can be kept apart to facilitate the erection of the rail shaped bars;

5. The roof fitted with these rolled bars.

The three parts of the shell having been entered into the rail shaped bars, the drilling, reamering and riveting is then done;

6. The vestibule ends and the safety devices, then the flitch plates of the roof sticks and lamp supports.

These operations finished, the side faces are electrically welded to the roof and to the frame sole bars.

A final correction of dimensions by shrinkage heating where necessary.

Finally, the inside metal surfaces are given a coat of paint.

The carriage is now ready for sand blasting, which is done over the whole outside surface in a closed-in building.

After removing all traces of sand, the body is mounted on its bogies.

It is then trimmed and painted.

The weight of the first class vehicle is 48.2 metric tons (47 tons 8 cwt.).

Conclusions.

The results obtained at the « Ateliers de Construction du Nord de la France » prove in a definite manner as we had affirmed beforehand that the methods we have just described can be applied industrially.

Their novelty might at first sight give rise to certain fears in the minds of the men who had to build them. These were dissipated by bringing over some of our own specially qualified staff and putting them to work with the Blanc-Misseron gangs. The quickness with which the latter learnt our methods, and the quality

of the work in the first vehicles, demonstrated the practical value of having done this.

The trial runs of the first coaches built, brought out as we had expected their remarkable steadiness, their smooth running at the highest speeds and when tak-

ing curves. We have no doubt but that in consequence the present maximum speed, of 120 km. (75 miles) an hour, can in future be considerably increased without this stock ceasing to possess to the same degree its qualities of steadiness and comfort.

[62. (01 & 669 .1)

Negative or reversed segregation and white stain,

By LOUIS PICHARD,
ENGINEER AT THE HAGONDANGE WORKS.

Figs. 1 to 5, p. 753 and 756.

(*Le Génie Civil.*)

When carrying out an investigation of a steel by means of a photographic print of a macrographed section, it is necessary to distinguish between the « negative or reversed segregation » characterised by the steady lightening of shade from the periphery to the centre, and the case of the « white stain » characterised by the presence of several concentric zones, one very dark surrounding the most central, which is very light. The reversed segregation is normal in bars from the foot of ingots, whereas the white stain is only found in bars from the top.

Negative or reversed segregation. — From the moment pouring ceases, or rather from the instant when the agitation caused by the spout of metal ceases in any region, solidification begins from the periphery inwards.

At first, the liquid is practically homogeneous. But soon after, in consequence of the phenomenon of liquation, the liquid is impoverished towards the foot as regards elements which rise upwards, whilst towards the head the molten me-

tal is enriched by the arrival of similar elements that have left the lower parts. Now the composition of the different solidified parts is a function of that of the liquid from which they are formed : there will then be in the foot a decreasing content of impurities from the periphery to the centre, and towards the head an increasing content thereof. This characterises the segregation which is negative or reversed in the first case, direct in the second.

Let us suppose that two sections cut, one from the foot and the other from the head, are treated with iodine. The first ought to shew a lighter zone at the centre where it ought to be impoverished in elements, especially carbon, revealed by this reagent : the second will generally shew zones increasing in tone depth from the periphery inwards. In this case then, the existence of a clear zone will indicate that we are dealing with a rail from the base of the ingot.

White stain. — Let us quote first of all the remarkable theory put forward by Mr. Howe at the « American Iron and

Steel Institute » Meeting in 1915, on the commercial production of sound and homogeneous steel :

« *Two types of solidification.* — We can conceive two extreme types in the methods of solidification of a mixture (heterogeneous alloy) :

« 1. The *bulb* or (*onion*) *type* characterised by the deposit of successive concentric layers;

« 2. The *arborescent* or (*land locking*) *type* characterised by the gradual invasion of the liquid zone by branch or tree forms growing from particles already solidified.

« In this second system, this crystalline segregation in continual growth ends by actually insulating pockets of molten metal, which are in fact the residue of the formation of these branches, and which consequently contain all the carbon, phosphorus and sulphur previously rejected when the crystals separate out. The result is that these latter elements find themselves in the position of being unable to re-assemble together in a last central pocket solidifying at the end. This process of the solidification would prevent segregation occurring throughout or at least would hinder it (we refer to the central or axial segregation).

« The fact of the liquid being still provokes this growth of tree forms for two reasons. The first molecule of steel precipitated is much poorer in carbon than the molten metal giving birth to it, and consequently the remainder of the molten metal is enriched in carbon round this solid particle. In consequence of enrichment its point of solidification moves away, by lowering, from the surrounding temperature. More steel cannot precipitate itself on the solid parts already formed, and it becomes necessary to wait from a slow diffusion a new distribution of carbon, allowing solidification at the existing temperature.

« Now let us imagine a group of arbo-

rescent forms striking into the heart of the molten mass: as we have just seen, by their very growth at their contact they have enriched the liquid in carbon. Now the diffusion of carbon is difficult towards their roots in the tangle of their branches and, on the other hand, is very easy towards the heads: the result is that these latter have greater facilities for their development.

« The same reasoning shews that the smallest projection is better than the hollow surrounding spaces, its growth is helped, and it rapidly becomes a node of considerable size.

« *The fact of the liquid being still hinders segregation.* — If, on the other hand, the molten metal is stirred up, this instability disappears, because the diffusion of the carbon is accelerated to all parts.

« The node is only of real advantage when the carbon from the too rich layers should be displaced by diffusion alone. If the solidification takes place very quickly, as happens with small section ingots, or the steel is poured so cold as to give up, before solidifying, only a minimum number of heat units to the walls of the mold, or again the molds are so massive that their temperature increases relatively little, then the advantage of the protuberances is under such conditions most marked. This is especially the case if the metal is quite still, since in this event the supply of metal able to precipitate itself is only obtained by the diffusion occurring over a very short period, so that segregation occurs least easily.

« These considerations lead us to think that the lack of movement of the metal does not favour segregation. As, on the other hand, the metal when still can easily remain liquid below the temperature of fusion, and that once this false equilibrium is broken, solidification takes place very quickly exaggerating the advantage of any nodes, we then get

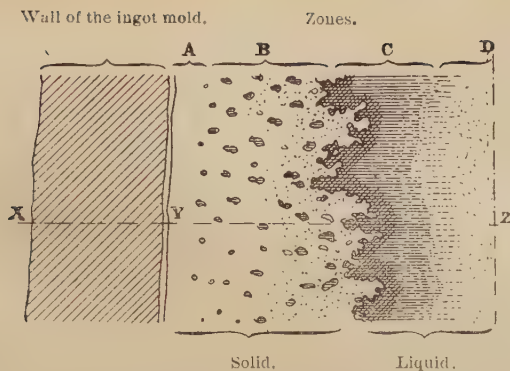


Fig. 1. — Part section of an ingot during solidification.

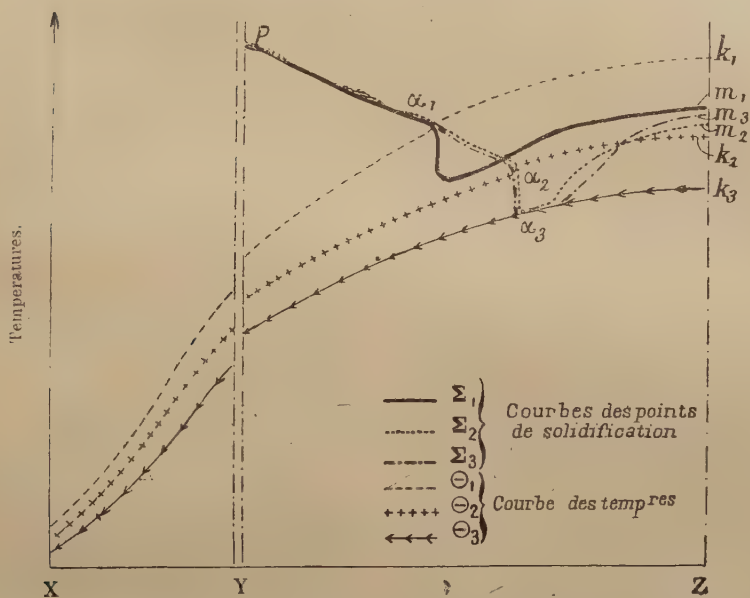


Fig. 2. — Graph showing the phases of segregation in the section XYZ (fig. 1).

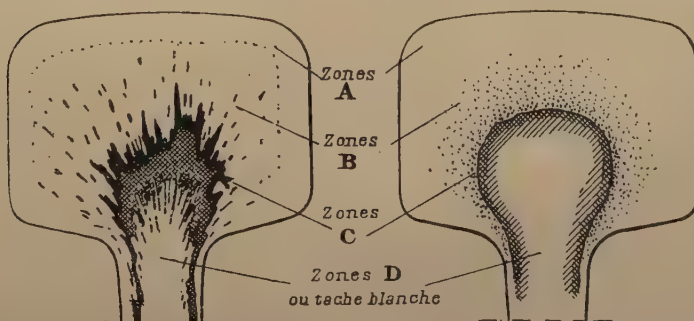


Fig. 3. — Macro-arborescent growth. Fig. 4. — Micro-arborescent growth.

Explanation of French terms in figures 2 to 4. Courbe des points de solidification = Curves of the points of solidification. — Courbes des temp's = Curves of the temperatures. — Zones D ou tache blanche = Zones D or white stain.

a considerable crystalline growth which in itself opposes segregation. »

Mr. Howe referred to the possibility of part of the metal remaining liquid at temperatures below that of fusion. Let us develop his idea, but in a different way from that he considered. First of all let us consider (fig. 1) a part of a vertical half section of the ingot during an arborescent solidification.

Starting from the ingot wall, we find :

1. A homogeneous layer A, the first to solidify and having to all intents the average composition of the cast;

2. A second layer B, containing small pockets of metal enriched in impurities imprisoned in the tangle of the arborescent growths. Most of these pockets, those near the wall, have solidified : the others, those just formed, are still liquid;

3. A zone of liquid metal C, highly charged with impurities, forming the mother liquor for all the heads of the arborescent formations;

4. Subsequently, and without any very clear transition, we find a central zone D, having sensibly the initial composition. In fact :

- a) The diffusion has not been able to spread so far so as to add to its impurities;

- b) Some impurities have migrated upwards, but have been replaced by others from below.

Let us endeavour to represent diagrammatically (fig. 2) the path of solidification in a cross section XYZ, for example. As abscissæ, we have the different points of the section of the ingot and of one of the walls of the ingot mold; as ordinates, we have the temperatures. At a given instant t_1 , we can draw two curves :

1. That through the points of solidification Σ_1 ;

2. That through the temperatures Θ_1 .

The curve Σ_1 has each of its points determined by the temperature of solidification of the corresponding metal, a temperature which is a function of the composition of the metal, which varies in one and the same point so long as this latter remains liquid. In consequence, Σ_1 decreases, starting from the wall p to the point α_1 where we find liquid metal as the whole of the solid particles desposited has become increasingly charged with impurities. When passing to the liquid metal the curve Σ_1 shews a sharp drop because the liquid metal is much more impure than the last cristal formed from it: then in the heart of the liquid mass, the curve of the points of solidification rises as it corresponds to regions in which the diffusion has had a more restricted effect and, actually, it passes through a maximum m_1 in the central region.

At the same instant, the curve Θ_1 , represents the distribution of temperature from the wall to the centre : it crosses the curve Σ_1 at α_1 which corresponds to the passage from the solid to the liquid zone : finally, at the centre, its maximum k_1 is above m_1 .

A certain time after, at the instant t_2 , the solidified region having extended and the temperatures having fallen, we have two new curves : Σ_2 and Θ_2 . From p in α_1 , Σ_2 follows the same line as Σ_1 , as the composition does not change : beyond α_1 it follows the same slope as from p to α_1 and at α_2 we reach the liquid metal where as before we again find a drop downwards.

At this same instant t_2 , we have curve Θ_2 , exactly like Θ_1 ; at α_2 , passage from the solid to the liquid zone, so that it crosses the curve through the points of solidification Σ_2 and on the maximum axis of the ingot k_2 . But the diffusion extending with difficulty so far as the central region and the quantity of segregated impurities from below being only able to lessen as the solidification of the lower

parts extends, the composition may have only changed but little. Then m_2 , the relative maximum of the curve through the points of solidification Σ_2 can only be near m_1 ; it may even be above it if there is a slight impoverishment due to the migration of elements upwards.

We can therefore imagine that there may be a reversal of the position of the points k and m : k_2 can be below m_2 which means that the metal ought to be in the solid state at the centre. Now we know that in such an event, there may be surfusion as the crystals rarely form without some starting cause: we have then at the centre of the ingot a pocket of liquid metal which continues to purify itself by the rising segregation, and at the instant t_3 , we have the curve through the points of solidification Σ_3 which differs slightly from Σ_2 after α_3 : it is at first below, due to the influence of diffusion, and then is above, as the result of the rising segregation.

At the same instant, the temperatures are shewn by the curve Θ_3 , and when Θ_3 no longer intersects Σ_3 , which means that the communication by solid elements is established between the exterior and the zone in surfusion, this false equilibrium suddenly ends and the central zone sets with such a composition that having few impurities it will be light coloured under the action of reagents when macrographing a rail section. This is the *white stain* due to segregation, but surrounded by zones of direct segregation.

Notes on the « white stain » and the two types of solidification. — The arborescent solidification is recognised by:

1. The many dark characteristic nuclei of the zone B, which are not « non-metallic impurities » as is sometimes said, but small metallic masses richer than the remainder in segregated elements;

2. The very marked delimitation of the zones B and C, the said line being

formed by the envelope of all the tops of the arborescent growths at the moment when diffusion ceases to play an active role.

The white stain has just been defined as being a fourth zone of this solidification. It certainly seems that its formation is rather unusual, at all events in the sections of ingots one is accustomed to examine. But does it only occur with arborescent solidification? Certain macrographs we have recently seen make us doubt it; there was no longer a zone A sharply separated from the zone B, but a zone AB of a shade increasing in darkness from the periphery towards the centre and, between this zone AB and the zone C quite black, the limiting line being regular, shewing at the rail head the well known characteristic rounded form. At the centre there was the zone D: the white stain.

We thought therefore that this white stain could also be produced during the bulb like solidification, but this made us reflect on the value of Mr. Howe's expression « two *extreme* types of solidification »; there might perhaps be only one kind of arborescent solidification, but this could be either « macro-arborescent » or micro-arborescent » (figs. 3 and 4) and outside this the bulb like solidification would be again found. It would then be no longer surprising to see the white stain when there was no macro-arborescence.

Particular cases affecting macrographs shewing the white stain. — This may be annular, that is to say, it may surround a fifth zone very dark in shade, indicating a high percentage of impurities.

The existence of this fifth zone is explained by the direct intervention of the other planes of the ingot. Actually, shortly before or during the phenomenon of surfusion in the region considered, it may be that the retraction of the lower parts which solidify may cause a large

demand for metal, and this can have two effects (fig. 5):

1. To take with it the most fluid portions of the plane under observation, that is to say, the metal from the zone C which will then be made thinner;

2. By the repercussion of the retraction on the upper parts, causing a downward flow of the liquid metal which may ultimately work its way to the centre where, when macrographed, it will appear under the form of a fifth zone of dark shade.

Is the presence of a white stain, when macrographed, in itself the indication of the bad quality of the rail under examination? — When under equal stress, a fissure occurs, it occurs either at the place where heterogeneity is most in evidence, or in the most unsound zone.

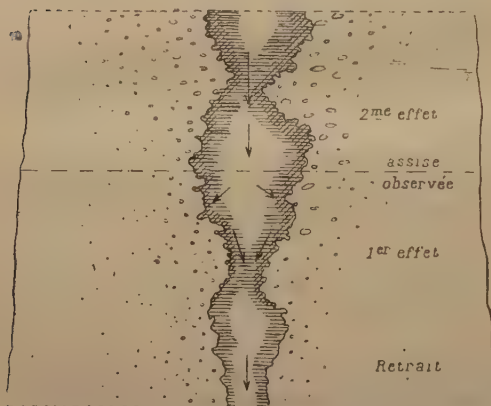


Fig. 5. — Movement of the liquid portions giving rise to a fifth zone segregated at the centre.

Explanation of French terms : 2^{me} effet = 2nd effect. — Assise observée = Plane under observation. — 1^{er} effet = 1st effect. — Retrait = Retraction.

Now where there has been *macro-arborescent solidification with or without white stain*, the separation of the zones B and C is in one case very well marked but in the other much broken up.

Considering it from another angle, the

first layers of the zone C encountered are the richest in impurities: there is then for this boundary between the zones B and C, if there is to be fissuration, the best conditions for the development thereof, especially if the said boundary pushes out a long point towards the rolling surface of the rail (fig. 3). It then matters little that the metal of the centre be segregated in the same proportions, or, on the contrary be relatively pure (case of the white stain) it does not come into play.

There still remains the likelihood of a micro-arborescent solidification, possibly bulbous; the boundary between the zones B and C is no longer irregular, but it always marks a serious variation in quality: it is still the kind that best lends itself to fissuration and, as in the preceding case, the sounder metal of the centre will continue to oppose it (fig. 4).

To resume, it is only the degree of segregation which can *a priori* be brought into comparison with the bad quality of the rails, and the white stain of itself does not come into question.

The white stain in ingots rolled before complete solidification. — We know that if samples cut from ingots rolled « young » *i. e.*, before they have completely solidified, are etched with iodine or the Baumann reagent, the white stain is found in all parts of the ingot other than the ends. But in this case, the white stain in the zone D instead of gradually at its periphery merging with the annular zone C, which is full of impurities, is more or less clearly detached therefrom. It seems that the effect of diffusion is entirely destroyed. We think in consequence that:

1. One ought to consider that during solidification, the co-existence in the remaining liquid of the two zones C and D is normal from the bottom to the top of the ingot;

2. As cooling off extends, the zone D ends by being in surfusion;

3. In consequence of the diffusion, the zone C absorbs the zone D, and the result of the mixture is a metal the richer in impurity as we get towards the top of the ingot;

4. Finally, the remainder of zone D can rest intact in certain parts until the surfusion ceases by normal solidification of the surrounding metal: this is the case we have described above;

5. Before it is absorbed, all the metal

of zone D can be artificially solidified by rolling the ingot too soon. This is the reason why ingots rolled «young» should shew the white stain or zone D, but without the diffusion having had time to lessen the definition of the contours, and on the other hand, the cessation of the surfusion affecting a less pronounced zone in unstable equilibrium would allow the impurities of D to separate out towards C similar to that occurring from B towards C, which gives a very well marked boundary between the two zones.

[621.392 (.75) & 624.32 (.75)]

First all-welded truss railroad bridge is put in service.

Figs. 1 to 10, pp. 758 to 763.

(*Railway Age.*)

One of the most recent developments in the field of bridge design and construction is the electric arc welding of all member connections, and while this method of erection has been used experimentally and in some bridge reinforcement work, we now have the first all-welded through truss railroad bridge to be put in service in this country. This new bridge, which is located on the Boston & Maine Railroad, has been built over a power canal at Chicopee Falls, Mass., on an important industry spur serving the Westinghouse Electric Company's plant at that point. While not a large structure, the bridge holds much interest for railway engineers, not only because it is the first structure of its kind in the country, but of more importance, because it points the way to certain de-

finite economies in bridge design and construction.

Introduced two years ago.

Less than two years ago arc welding was introduced into the field of heavy structural steel construction, but within the short space of time which has elapsed, such rapid progress has been made both in the use of structural welding and in understanding the theories surrounding it, that considerable interest has been aroused with regard to the adaptability of the arc welded joint in bridge structures, and as regards whether or not such joints will stand up under the stresses imposed by railway loadings and impacts. It was this interest which led to the construction of the Chicopee Falls



Fig. 1. — General view of the all-welded bridge just before it was moved into place.

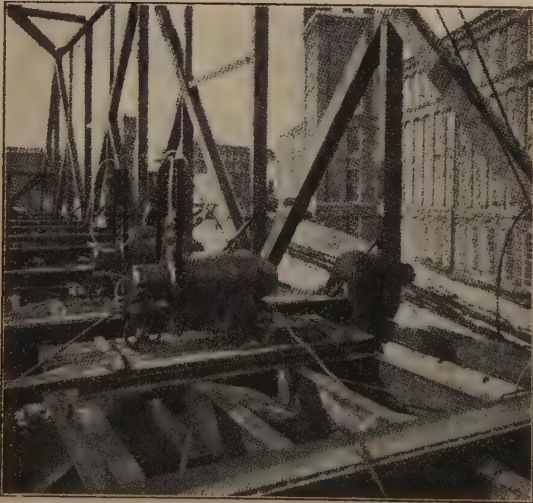


Fig. 2. — Two 200-ampere, one-man welding units accomplished all of the welding work.



Fig. 3. — A view between trusses showing the general arrangement of the bridge members.

bridge, a project which was carried out by the Westinghouse Electric Company, East Pittsburgh, Pa.

General description of the bridge.

The Chicopee Falls bridge is a single track, single span structure of the Warren truss type, with sub-divided panels, and owing to the angle of crossing of the power canal, has 72° skew. The length of each truss is 134 ft. 8 in., but owing to the skew of the bridge, its overall length is about 175 feet. The width of the bridge between trusses is 17 feet and the vertical height between the chords of each truss is 24 ft. 8 in. All members of the bridge are single structural shapes except the cast iron pedestals at the masonry abutments, and the floor beams, which consist of 21-inch rolled beams with welded cover plates. All chord and diagonal members of each truss are Carnegie wide flange beams of the 10-inch depth group. The other members of the bridge, including all bracings, are made up of an assortment of standard I-beams, Carnegie wide flange beams, angles and small H-beams. No channels were used in any part of the bridge.

Unit stresses allowed.

The Chicopee Falls bridge was designed for Cooper's E-50 loading. In working out the details of construction, standard unit stresses were allowed for all structural members, and the allowable stresses in welds were based upon experimental tests and actual experience in welding construction up to the present time. In the actual construction of the bridge, several types of welds were employed, principally with the view of determining the action of the various types under severe service conditions, and to determine ultimately the types of welds best suited for each type of joint in bridge construction. The three classes of welds used most extensively were

fillet welds, slot welds, and butt welds, tack welds and spot welds being used in

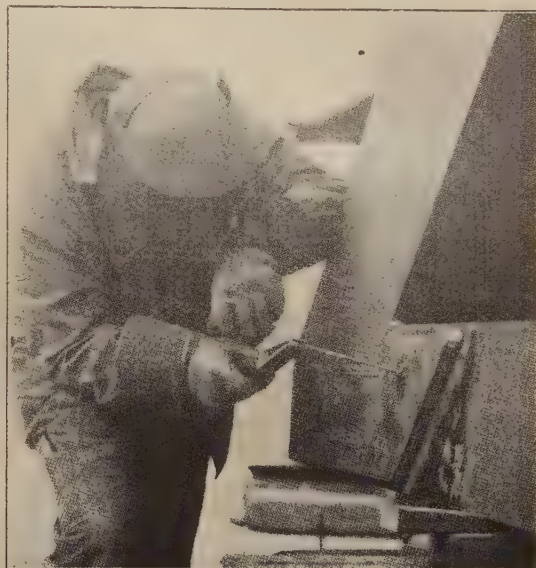


Fig. 4. — Welding the gusset plate on one of the lower chord end joints.

only a few instances and then principally for erection purposes.

In the case of fillet welds, 3/8-inch fillets were adopted as standard, and a unit stress of 3 000 lb. per linear inch of fillet weld was allowed in shear in any direction. In the actual design of the bridge it was found that various sizes of fillet welds could have been used, depending upon the strength to be developed at each particular joint. Owing to the difficulty of accurately determining the size of the weld as it is being built up in the field however, it was thought advisable to standardize on the 3/8-inch fillet weld and thus avoid the possibility of confusion. All of the slot welds are 1/2-inch by 1/2-inch in section, with an allowable unit stress of 5 000 lb. per running inch of weld.

This latter type of weld is unusually

compact, which accounts for the high allowable unit stress, wherein 1 1/2-inch of the slot weld is equivalent approximately to one 7/8-inch rivet in single shear. It will be noted also that the value of the 1/2-inch by 1/2-inch slot weld was figured at almost twice that of the 3/8-inch fillet weld. In using the butt type weld, a unit stress of 13 000 lb. per square inch of weld was allowed.

Details of more important connections.

Reference to the accompanying detail drawings will show clearly the more important connections made in the bridge and the type of welds used in each case. Figure 5 shows a lower chord panel point with its gusset plates and welds. Here, slot welds connect both the chord and web members to the gussets, transferring tension or compression stresses from the flanges of the members directly behind the slots, to the gusset plates at both edges of the slots. It will also be noted that triangular fillet welds assist the slot welds by transmitting stress from the edges of the web member flanges to the inside face of each gusset.

Figure 5 also shows a bottom chord splice. In addition to two splice plates, which are joined to the chord members by fillet welds acting in shear along the top and bottom edges, the abutting ends of the two sections forming the lower chord are butt welded together, the weld having the same cross section as the smaller chord member. Since a tensile stress of 13 000 lb. per square inch was allowed in the butt weld while 16 000 lb. per square inch was allowed in the chord members, it is evident that the butt weld may be assumed to take care of 81 % of the splice load, while only 19 % is left to be carried by the splice plates.

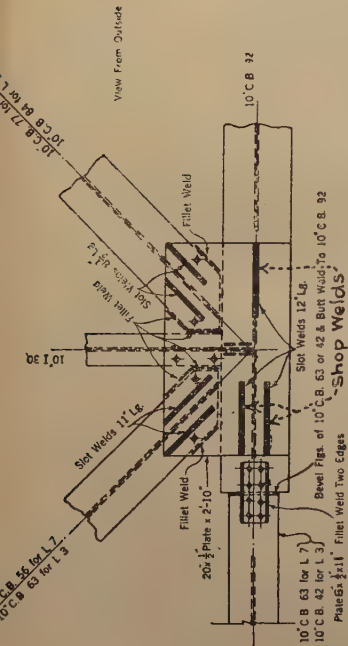
In forming the butt weld at this point, the flanges of the lighter chord member were bevelled on the outside edge at the end, at an angle of 45°, and the web of this member was bevelled on the top face

to the same extent in order to facilitate making the weld. In actually making this joint in the lower chord, the splice plates were first used for erection bolting to hold the members in alinement while the butt weld of the chord webs was made. Following this weld, the plates were removed while the flange welds were made, and then the plates were replaced and fillet welded to the chord members.

The type of bottom chord panel point connection shown in figure 5, making use of gusset plates, occurs only at two points in each truss, these being the first panel points each side of the mid span. All other panel point connections at the lower chord, with the exception of the end joints, were made without the use of gussets. Figure 6 shows one of these joints, from which it will be noted that butt welds alone are used, connecting the upper flanges of the chord member with the flanges of the intersecting web members. The three small plates shown in figure 6 were fillet welded to the chord member in the shop and were used solely for erection purposes.

Figure 7 illustrates the method adopted in making a lower chord end joint. Here, in each case, the chord tension is developed by slot and fillet welds at 1/2-inch splice plates, and by butt welding of the flanges only at the junction of the chord member and the end post. The end post was bored in the shop for the 4 1/2-inch pin shown, which is held in place by a shop fillet weld connecting the pin to the web of the end post. By so welding the pin in place, the ends of the pin could be cut flush with the sides of the end post, and the need of pin nuts was eliminated.

The pin pedestal, consists of an assembly of plates welded together in the shop. The main bearing pedestal is an iron casting, selected for this particular job, rather than a steel casting because of its superior rust resisting qualities.



Outside Elevation

with gusset plates.

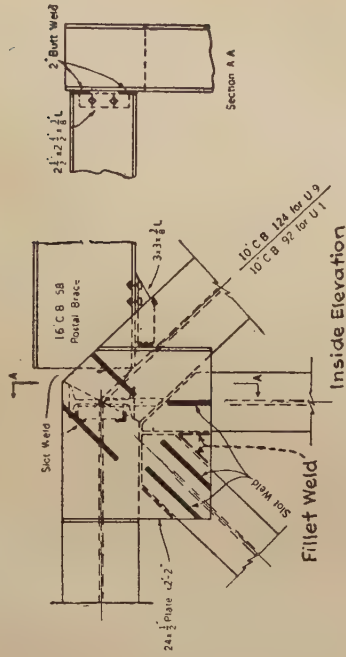


Fig. 8. — Detail of hip joint where gussets are used.

Fig. 8. — Detail of hip joint where gussets are used.

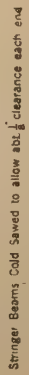


Fig. 9. — Welded connection of stringers to floor beams.

The details of the hip joint are shown in figure 8. Here the ends of the upper chord and end post are milled and butted together. The gusset plates used at this point are both slot and fillet welded to the members as shown, their principal functions being to transmit the web member stresses and to hold the chord and end post in position.

Floor system of unusual design.

In designing the floor system of the bridge, 21-inch rolled I-beams with welded cover plates were used for floor beams. The connection of each floor beam with the lower chord is a triangular butt weld between the inside flange of the chord, the post at the panel point, and one side of the web of the abutting floor beam. These welds have a minimum section of 5/8-inch by 18 inches, and are designed to resist a shear slightly less than 100 000 lb. Supplementing the butt weld, fillet welds were also made between the inside flange of the lower chord member and the lower flanges of the floor beam. As already mentioned, the butt weld at the floor beam — lower chord connection, is on only one side of the floor beam web. On the opposite side is a small angle, tack welded to the floor beam, and used solely for field erection.

Each floor beam joint is provided with a single angle knee brace at 45°. This detail was given special consideration in view of the inflexible character of the knee brace connection, which consists of direct welds between the brace and the members. In designing the brace, calculations were made to determine the approximate tension in it due to the resistance of the stiff vertical truss member against deflection inward, with the flexure of the floor beam under live load.

The four lines of 12-inch I-beams serving as stringers are designed to act as continuous beams, this being done for two principal reasons; first, to reduce

the bending moments and thereby permit the use of lighter stringers; and second, because welded connections between stringers and floor beams necessarily introduce a degree of rigidity that would imply a considerable continuous action. Adopting this design, the stringers used are connected at the floor beams as shown in figure 9. Here the floor beam web is slotted to pass a tension bar connecting the top flanges of opposite stringers, these bars being joined to the stringer flanges by fillet welds along each side. In addition to the tension bar, compression plates or bars are welded under the bottom flanges of the stringers and are butted against the floor beam web. Fillet welds between the ends of the stringers and the web of the floor beam carry most of the vertical reactions and also assist in resisting the negative bending moment at this point. A minor fraction of the vertical reaction is considered to be transmitted through the erection filler blocks shown in the drawing.

Owing to the fact that obstructions were not permitted in the power canal at Chicopee Falls, except during week ends when industries were shut down, it was necessary to erect the bridge on blocking, on one side of the canal, and then to pull the completed structure into place on the abutments. In the actual construction of the bridge, two welders alone were employed, assisted by common labor for handling the members and for placing and removing scaffolding.

The welding equipment used in the work consisted of two Westinghouse single-operator welding sets, each with a rating of 200 amperes. These sets are particularly designed for speed and adaptability in structural welding. The welding current of the generator is controlled by turning the handle of a single dial rheostat in the field circuit, a turn of the handle setting the desired current for welding operation. The arc produc-

ed by the welders is easily struck and easily maintained, the generators being designed to respond instantly to voltage variations caused by changes in the

length of the arc. Special bearing construction in the welding units used, enables them to operate satisfactorily while tipped or inclined on almost any angle,



Fig. 10. — The first train passing over the bridge.
View shows the excessive skew of the structure.

and the three-wheel carriage provided makes the units steady on the most uneven footings.

Little difficulty was experienced in any part of the actual construction of the bridge. Mild steel wire was used for making all welds. Erection bolts were used for all stringers, floor beams, main truss members and bracing mem-

bers too heavy for two men to handle without a derrick. When the bridge was completed, blocking was erected in the power canal during low water over a week end, and the bridge was pulled into place by horse-operated capstans. When in final position, the railroad track was laid, and shortly thereafter, the first locomotive was moved over the bridge.

A generalized method for traverse surveys in open country, ⁽¹⁾

By ARTHUR HENRY DOUGLAS, M. C., B. A., B. A. I., Ass. M. Inst. C. E.

Figs. 1 to 16, pp. 766 to 785.

This paper describes a simplified method of making large- and small-scale traverse surveys in open country, with the minimum of expense and the maximum of topographical detail, using standard instruments and apparatus only, together with a uniform method of recording results in the ordinary pattern of stadia field-book. The work on which it is based was carried out by the Author and others in North China between 1923 and 1925, in connection with the survey of proposed extensions of the Peking-Mukden Railway beyond Pei Piao to Chao Yang, Hata, and the North. The construction of the first portion of this new branch line has already been described ⁽²⁾ by Mr. Harold Stringer, Assoc. M. Inst. C. E.

Although satisfactory instruments designed for particular duties can be procured, the Author was restricted to the standard forms of instruments and apparatus normally available, such as the transit theodolite, slide-rule, stadia staff, ranging-rod, stadia field-book, etc.; and he set himself to develop from first principles a uniform method of working with these implements which would be equally applicable to survey work at 10 000 feet to the inch and 400 feet to the inch, at 25 miles a day and 1 mile a day, respectively. The method to be described

has been well tested by the Author and various foreign and Chinese engineers in North China during the last three years, and has produced good results.

Although no claim is made for originality in the detailed means employed, nevertheless information regarding them is scattered through so many books and papers that it is seldom available when wanted; and the Author was led to the conclusion that simplification was a more urgent duty than new invention in this branch of engineering at the present time.

The first section of the paper briefly reviews the general principles underlying traverse survey work. This is followed by a description of three typical forms of railway survey work, namely, preliminary survey as a basis for paper location in the office, flying traverse survey for the rapid comparison of rival routes, and first reconnaissance survey undertaken to furnish a rough estimate of expenditure and revenue on the proposed construction. These surveys are given in the reverse order to that in which they actually occur in the field, in order to facilitate a logical development of the subject.

For the sake of argument the scales of the three surveys have been taken at 400 feet, 2 000 feet, and 10 000 feet to the

⁽¹⁾ Abstract of Selected Engineering Paper No. 49, published by the *Institution of Civil Engineers*, London, 1927.

⁽²⁾ "The Pei Piao Extension of the Chaoyang Branch of the Peking-Mukden Railway" (Abstract in *Institution of Civil Engineers Sessional Notices*, 1925-1926, p. 70).

inch, respectively; and the average speed of execution at 1 mile, 5 miles, and 25 miles per diem.

Although the Author has illustrated his remarks with examples from railway work only, he believes that the subtense method is capable of much wider application; for in practice owing to transport and other difficulties, pioneer survey work of every class usually resolves itself into a series of separate traverses, even when it embraces a wide area of country. Further, of the remaining unmapped portions of the globe in which such pioneer work still remains to be done, vast stretches consist of just that kind of bare hilly country which is best suited to the subtense method of traversing, in which the transit theodolite is given its rightful place as the primary instrument of survey.

General principles.

The essential difference between triangulation and traversing lies in the ratio between the measurements made in the two horizontal dimensions. In the former, this ratio approximates to unity, and one direction is as important as the other. In the latter, the more important direction is that of the traverse itself. The subtense form of traverse survey described in this paper is best considered as a special case of triangulation survey, arrived at by reducing the ratio between transverse and direct horizontal measurements from unity to a fraction ranging between $1/50$ and $1/200$. In triangulation survey the base lines, which are measured directly, are used as a basis for the indirect measurement of the remaining distances between main stations, by angular observations with a theodolite. In the primary triangles so formed one distance and two angles are given and the remaining elements are calculated. The ideal shape for that triangle is equilateral. If one set of horizontal dimensions are reduced to 1 % of

their previous values, the primary triangle of the triangulation survey becomes the « subtense triangle » of the traverse survey. This reduction in one horizontal dimension simplifies the solution of the subtense triangle by permitting the use of circular measure, in lieu of sine and tangent, for the vertex angle; a further simplification is usually introduced by making one of the base angles a right angle.

The subtense triangle, then, may be defined as one in which a small measured base and vertex angle are used for the indirect determination of distance. From this distance differences of height are determined by the solution of a second triangle in which the vertex angle (usually small) is the measured slope between stations, and one of the base angles is always a right angle. Thus the two triangles on which the complete subtense survey depends bear a close resemblance to each other, the method of solving the second being the converse of that of the first. These two triangles will be referred to as the « distance » and « altitude » triangles of subtense survey work.

Whether the base is measured vertically, as in ordinary stadia work, or horizontally, as in faster forms of subtense survey, does not affect the principles; further, the horizontal base may be measured at either the sighted or the occupied station. In practice, however, these variations give rise to three distinct cases, which adapt themselves readily to the requirements of the three typical forms of railway survey described in this paper; between them they cover the whole range of pioneer survey work, as indicated in figures 1 to 3. The scales, distances, and vertex angles there shown mark the usually accepted limits for each class of survey.

The Author is aware that the word « subtense » has hitherto been restricted to the particular triangle in which the base is a fixed distance of 10 or 20 feet,

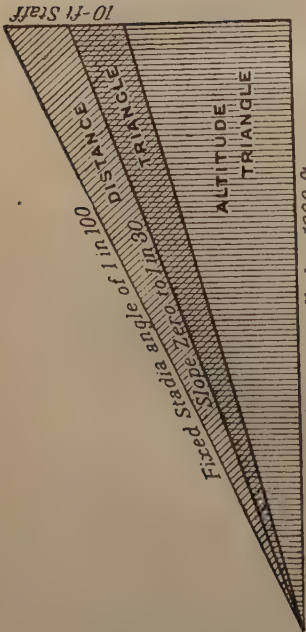


Fig. 1. — Preliminary traverse.

Scale: 1 inch = 1 000 feet or less.

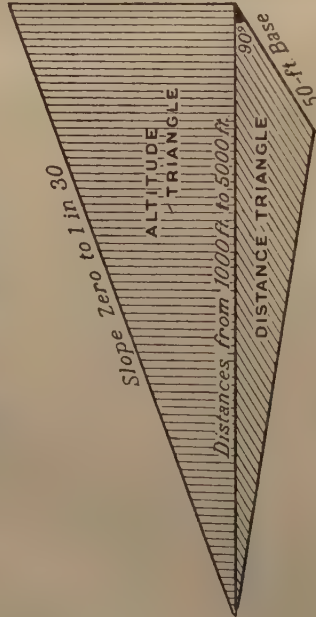


Fig. 2. — Flying traverse.

Scale: 1 inch = 1 000 to 5 000 feet.

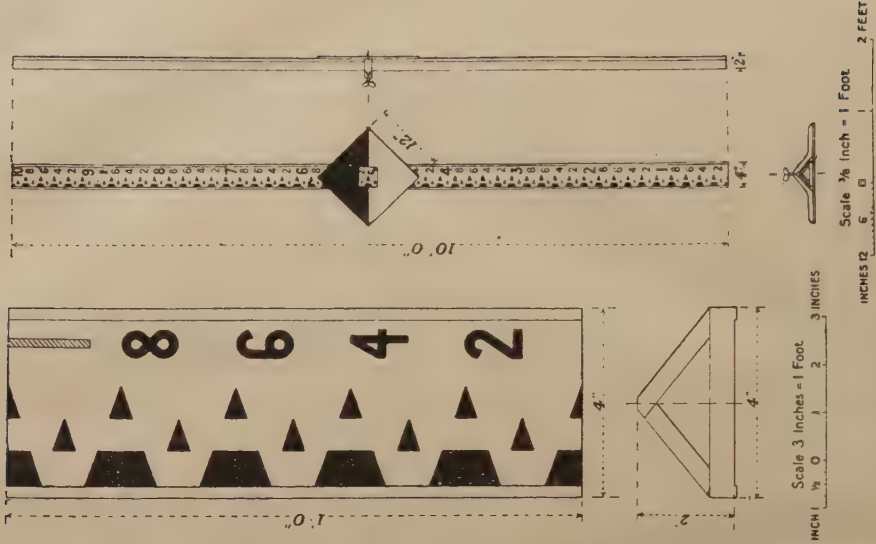
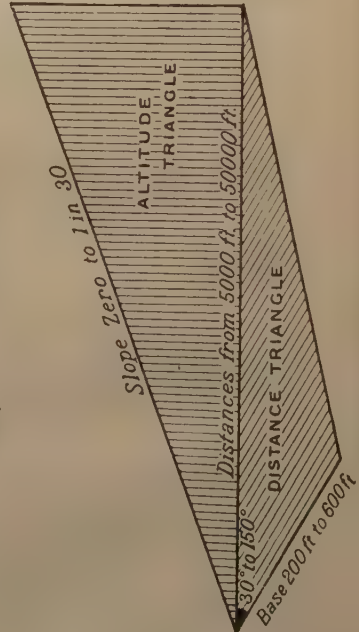


Fig. 4. — Universal staff.

and the vertex angle is measured with great accuracy by means of a micrometer eyepiece, or by numerous repetitions on the horizontal circle; but the dictionary definition and the lack of a suitable alternative appear to justify its wider use.

Typical railway surveys.

a) *Preliminary traverse survey.*—This class of survey is based on the best known example of subtense work, namely stadia survey. In its original form, stadia survey work involved complicated reductions which, together with the imperfect forms of tacheometer then available, prevented it from coming into wide practical use. Various means have now been adopted to overcome these difficulties, of which the latest is the direct-reading tacheometer. The necessary reductions, however, can also be made with a speed and accuracy sufficient for most purposes by means of a stadia slide-rule; and this offers a cheaper solution to those who already possess good standard theodolites equipped with stadia wires.

While any form of stadia staff with open readings can be used, the Author considers that the form of staff illustrated in figure 4, which is equally suitable for stadia work and for precise levelling, possesses important advantages not found in any other pattern. This form of staff embodies the same principle as the diagonal scale, that is, it magnifies small vertical intervals in the ratio of the cosecant of the angle of slope. In the example given, the angle of slope is 20° , giving a virtual magnification of nearly $\times 3$ to each tenth of a foot. This interval is divided into five elements of 0.02 foot each; thus the staff can easily be read to 0.005 foot by estimating quarter points in any element; at the same time, the elements are sufficiently boldly set out to give clear readings under all conditions of stadia survey. Even for

the most precise levelling encountered in railway work the Author prefers this staff to the more conventional patterns reading directly to 0.01 foot. The modern tendency is to reduce the number of marked divisions to a minimum, and to rely more on interpolation, aided by improved optical design of telescopes and eyepieces. The extra clarity achieved by this practice more than compensates for any personal errors introduced.

The stadia staff was employed by the Author only for main-station readings. For subsidiary shots an ordinary 10-foot ranging-rod usually sufficed. The generating number was estimated directly to 0.1 foot (to the nearest 10 feet in distance) on the red and white markings of the rod; height of instrument was taken as 5 feet, and the centre wire was placed at this height on the rod before the vertical angle was read. In all subtense work the Author prefers, wherever possible, to set the centre wire to the height of instrument on the staff or target at the distant station. With reciprocal working (forward and back readings between each pair of main stations) this method not only simplifies booking and reduction work, but provides a system of immediate checks on the accuracy of the field work, because the sum of the stadia-wire readings for any one observation should equal twice the height of instrument, and the forward and back vertical angles between any two stations should be the same.

The elimination by reciprocal working of cumulative instrumental errors is annulled by the common practice of transiting the telescope for back sights, which causes a double reversal of conditions whose net effect is to reinforce the forward-station errors instead of to cancel them. For astronomical work and for instrumental adjustment the transit principle is invaluable; but for ordinary working the Author favours an absolutely consistent employment of the

horizontal circle throughout, with the telescope always in its normal position. Of course, instrumental errors can be eliminated by combining « face-left » and « face-right » readings, as in astronomical observations; but in practice this tedious method is only used to prolong straight lines, and even for that the Author has discarded it in favour of the direct use of the horizontal circle in all ordinary traverse work. His early attempts at « double-centering » with native labour usually ended in his having to ride forward to ensure that his signals had been properly obeyed; whereas the setting of an exact 180° on the circle, involving at most a compensating error of (say) 15 seconds of arc, is under the direct control of the instrument man himself. The Author cannot believe that it is possible to « spot » a compensating error of this magnitude on the finished road or railway however long the tangent may be.

Stadia results are usually booked on a form of field notes which appears to be fairly well standardized, and it has therefore been adopted by the Author for all forms of subtense work, with various minor modifications, which do not interfere with the utility of the book as printed. The most important of these amendments are the addition of a column for magnetic bearings, and the separation of main-station and subsidiary levels. All horizontal angles are read as whole-circle bearings, referred to true and magnetic north respectively in separate columns. From these two sets of readings a permanent record of total magnetic variations is obtained, which (in addition to its immediate value as a check against gross errors) often proves useful later in picking up lost stations, starting new traverses, and so forth, and is usually welcomed by Government geologists and surveyors for their records.

Spot levels should be chosen so that the slope between any two varies appro-

ximately uniformly, allowing of interpolation in any direction. The Author prefers this method to contouring, because it is easier to distinguish the accurate portions of the map from those which are merely sketched. The tendency with contouring is to reduce the whole map to flat level of relative inaccuracy, which fails to give the governing points their proper weight during subsequent study in the office. Two adjacent spot levels, on the other hand, are a clear statement of the surveyor's belief, from actual study of the ground, that no feature of engineering difficulty exists between them; for if it did, he would have honoured it with an extra spot level. The ability to examine the ground with a « cubist » eye is soon acquired, and is, indeed, the essence of all topographical work. In order to facilitate the interpretation of the spot levels, a small amount of hachuring is added from information given in the remarks column of the field notes (which should always be as full as possible).

Most of the Author's preliminary survey work was carried out in winter, in a shade temperature ranging from 0° to 32° F., varied by the effects of sun and wind. Besides reducing the rate of working (gloves, and sometimes goggles, had to be worn for protection) this led to several important changes of procedure, though not of principle, which are referred to later. However, an average rate of one mile a day was attained on most occasions, so this figure has been adopted in comparing it with the faster forms of survey described in the two following sections. Seeing that much of the work was carried out on soft friable ground intersected by deep and narrow gullies with almost vertical sides, it is evident that nothing like this speed could have been achieved by a chained traverse.

As already stated, the results of such a survey are finally embodied in notes

giving all the elements of the proposed railway location, worked out to the same degree of accuracy as that of the preliminary survey. The Author tried the experiment of locating a 10-mile stretch of line near Pei Piao in the field purely from these notes, running each curve in directly by means of its (previously calculated) long chord, or by the use of suitable random points, and ignoring the intersection-points; the preliminary pegs were used (both in the field and on the plan) merely as an occasional check against gross error. His experience is that this method is quicker, more accurate, and more elastic than any which depends on direct measurements from the plan coupled with field location of intersection-points, if the notes are carefully compiled; its advantages more than compensate for any extra time spent in the office in making the necessary calculations.

b) *Flying traverse survey.* — The Author recently completed in about a fortnight the field work for a comparison of two 25-mile routes in hilly country near Chao Yang, by using a variation of the method of subtense survey adopted many years ago in North China by Mr. C. W. Kinder, C. M. G., M. Inst. C. E., for the location of the Peking-Mukden line. In this method main traverse lines a mile or more in length may be used for the skeleton of the survey, by stretching a 50-foot tape (set approximately at right angles to the line of sight by means of an optical square or cross-staff) at the forward station, and taking a single reading of the subtense angle on the horizontal circle. The ends of this measured base line are marked by ranging-rods equipped with flags. Independent of the base line, but in the same general position, is erected a stadia staff carrying a 12-inch target clamped 5 feet from the ground; horizontal and vertical angular readings are taken to this target to determine the direction and

elevation of the distant station. The erection of the target should be delayed until everything is ready for readings to be taken; otherwise misunderstandings may occur between the base-line and instrument parties, owing to the increased distance between stations. The former party should be supplied with binoculars, to enable them to keep touch with the instrument station by means of signals, in case of unforeseen difficulties with regard to obstacles, background, etc. These disabilities led the Author to abandon the use of the more orthodox 100-foot base in favour of one of half its length, for this class of traverse work, with (he believes) little diminution in accuracy.

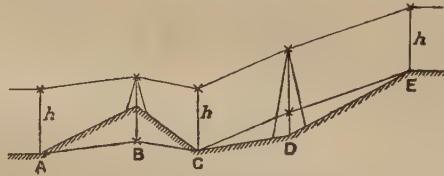


Fig. 5. — Even stations.

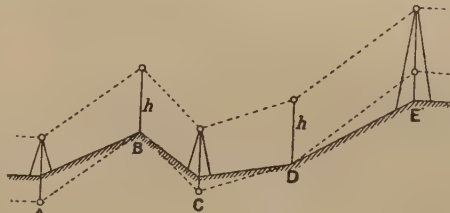


Fig. 6. — Odd stations.

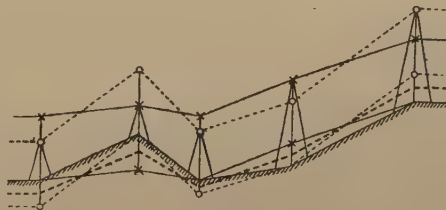


Fig. 7. — Reciprocal working.

If reciprocal working is adopted, much time can be saved by omitting to measure the height of instrument; the error intro-

duced by assuming that its value is constant is both small and non-cumulative. Consider any five stations of a traverse survey (A, B, C, D, and E in figures 5 to 7); if the instrument were set up only on every second station and back and fore sights were taken at each setting, the levels of staff stations would always be correct, and the errors at instrument stations would be the algebraic differences between the various heights of instrument and the constant height of the target. There are two cases for this way of working, and in practice they are combined together as shown in figure 7, the instrument being set up at every station. Thus the final error at any station due to error in height of instrument is only half the difference between the height of instrument and height of target. It seldom exceeds 0.5 foot in practice, and is independent of the distance. Horizontal and vertical reductions for flying traverse surveys are made on the ordinary slide-rule, using the factor 3437 (which should be specially marked on the sliding scale) to convert the vertex angles, expressed in minutes, into circular measure.

Spot levels for topographical detail are made by stadia shots on 10-foot ranging-rods, as already described, estimating tenths of a foot on the red and white markings of the rod. By this means shots up to 2 000 feet or more on either side of the main traverse line can be taken with an accuracy commensurate with that of the survey as a whole. Chinese coolies soon become expert at choosing positions for spot levels; and the instrument man controls the survey from the instrument, an advantage which will appeal to all who have worked with foreign labour.

Although flying traverse surveys are usually run on the circle in the ordinary way, using whole-circle true-north bearings, it is found convenient to alter the order of procedure in the field, by set-

ting the circle directly from the compass-needle at each station, leaving true bearings to be calculated afterwards by subtracting the amount of the local magnetic deviation; the latter, which is simply the difference between true fore-sights and magnetic back-sights, is entered in a column of the field book as a permanent record. This way of working makes the instrument man more independent of the rear-station party; in fact he can carry on without them at any time by running his lines as a free compass traverse, without any alteration of procedure. In addition, the list of deflections provides a constant check on the accuracy of the work in districts unaffected by local attraction, and is a useful measure of the magnitude of the latter where it does exist.

Pegging of stations is usually omitted on flying traverse surveys; this results in an important saving of time, especially on rocky or frozen ground. Stations are merely temporarily marked, for the benefit of the instrument and rear-station parties. Future traverses can be started from the nearest prominent object marked on the plan, using the same local magnetic deviation as before, without any appreciable error in the result. None of the errors of this form of survey becomes appreciable till the length of the traverse exceeds 15 miles. Since this result can be achieved without the use of pegs, plum-bob, or measured height of instrument, at an average rate of 5 miles a day including topographical work, it is surprising that such a powerful weapon of investigation should not be more widely used by railway locating engineers. In the course of the work near Chao Yang referred to, the Author closed a 40-mile traverse with a total horizontal error of less than 500 feet, though part of it was run by means of a circular compass marked only to single degrees. The corresponding vertical error of 8 feet was partly due to an

unusual form of instrumental defect referred to later. Another traverse, 10 miles in length, for which a perfect instrument was used, closed with a vertical error of only 1 foot. These results are due to the fact that reciprocal working eliminates most of the instrumental and other errors incidental to trigonometrical levelling with the theodolite; thus results can be produced whose accuracy will surprise those who have not previously experimented with this method of rapid levelling. Forward and back angles between main stations should be sensibly the same, giving an immediate check against gross errors. The mean of forward and back readings is used in calculating heights and distances between main stations.

The ordinary stadia book can readily be adapted to suit the flying traverse, and either method can be used at will. The « wire » readings to main stations are, of course, the magnetic bearings to the two ends of the measured base line, read directly off the horizontal circle; and the « generating number » is the vertex angle thus obtained. Not only the main-station results, but also the stadia readings to subsidiary points, can be reduced by the ordinary slide-rule without sensible loss of accuracy, provided the vertical angle is fairly small, by reducing the latter to minutes and using the factor 3437 in the usual way.

Using the flying-traverse method, a Chinese cadet engineer, assisted by one Chinese student and a tracer, was able to cover 5 miles a day up a rocky riverbed, and to plot a map the same night, upon which the maximum length of development of a railway-line and the length of tunnel required at the top of the pass could be estimated, and a useful estimate was made, in addition, of the dimensions of banks, cuttings, and bridges, for comparison with alternative routes.

reconnaissance for a long line of road or railway, or for the preparation of a rough map of hitherto unexplored country, should proceed at the same rate as the available means of transport, say 25 miles a day. The Author recently was responsible for such a survey for 300 miles of railway from Chao Yang to the border of Mongolia. The only available map was to a very small scale and of doubtful accuracy. It is desirable in such a case to map the routes taken with sufficient accuracy to enable reliable deductions to be made afterwards regarding the intervening country, since this frequently saves traversing that portion, and serves to fix promising routes straight away within narrow limits. For this purpose distances based on speed or other estimates are too rough; direct measurement is too slow; and cyclometer measurements are too devious, because they must generally follow the native roads. To meet these conditions, a method of using the transit theodolite was evolved, analogous to the two mentioned in the preceding sections, which produced good results under weather and other conditions exacting enough to be considered a fair test. In this form of subtense survey the base line is measured at the occupied station by ordinary stadia methods, so that a main and a « satellite » station 200 to 600 feet apart are quickly fixed, from each of which a round of horizontal and vertical angles is taken to distinctive mountain peaks, etc., up to a distance of 5 miles or more along the route to be surveyed, and somewhat shorter distances on either side. At the main stations the horizontal circle is set to read magnetic bearings, by means of the trough compass. At the satellite stations the circle is set by a back sight along the subtense base line, the compass being used merely as a check against gross error. The difference between the two sets of readings from the main and satellite stations gives

c) *First reconnaissance survey.*—Fast

the vertex angles of the subtense triangles, and the difference between either set and the magnetic bearing of the stadia line gives the base angles concerned in their final reduction. Reductions are first made by the ordinary slide-rule in the same way as has been described for the flying traverse survey; afterwards each result is multiplied by the sine of the base angle subtended at the satellite station, to correct for the obliquity of the measured base to the line of sight.

Levels are carried forward by using prominent peaks as turning-points. Discrepancies between results from different peaks are averaged, and the final results are checked against barometric levels. Reciprocal working is not possible in this kind of survey (except in the modified form implied in the shooting of two or more peaks from the same station), but, instead, a complete series of checks on angles and distances is obtained by astronomical and atmospheric means (in both of which the error is largely independent of distance). That is, latitude and azimuth are checked simultaneously nearly every night by the North Star (azimuth at culmination being sufficiently accurate as a check on average magnetic deviation during the day), or separately by sun and stars; and heights are checked by readings on the aneroid barometer, corrected for temperature and weather in the usual way. Neither the type of country traversed by the Author, nor the wheater encountered, was conducive to successful application of the « latitude and azimuth » system of survey, though the direction (north-west, and afterwards almost due north) was favourable for accurate results.

Long and accurate azimuths were secured, whenever possible, from sun observations. On one particularly clear day, the Author picked up a known peak 40 miles away, but the sun was then too low to secure its true azimuth; its approximate azimuth, however, agreed clo-

sely with the plotted survey. As a contrast to this experience, another whole day was spent in a dust-storm of such violence that it was impossible to see the road 10 feet ahead. On the following day, however, three back-sights on known peaks sufficed to put the party on the map again, with the same degree of accuracy as that secured in the remaining links of the chain.

As regards the degree of accuracy of astronomical observations carried out with an ordinary vernier theodolite, if the probable error of a single observation on the North Star is taken as 20 seconds, the probable error of a set of four readings (taken two face-left and two face-right to eliminate instrumental errors) will be $\frac{1}{4}\sqrt{4}$ of this, or 10 seconds.

Successive star observations by the Author at the same place always agreed within 10 seconds, corresponding (for latitude) to 1 000 feet on the ground; but the average discrepancy between different sun observations was double this amount, owing to personal errors in sighting the moving sun against the cross-wires. Both these results, however, were accurate enough for the purpose in hand. During the first part of his reconnaissance survey, the Author met a Belgian priest who had compiled an excellent map of the principal towns and villages in the whole district covered by the railway survey by means of star observations for latitude and (relative) longitude with an « astrolabe » of French pattern, carried during his various journey on mission work. Although time did not permit of more than a rough comparison between the two maps, none of the discrepancies discovered in longitude exceeded a mile. Discrepancies of latitude were, of course, much smaller.

Topographical details are secured partly from main theodolite stations as already described, and partly by similar ob-

servations with portable instruments, using previously-determined mountain peaks or passes as fixed points. The box sextant now takes the place of the theodolite for measuring distances; the prismatic compass is used for measuring bearings, and the Abney level (checked by aneroid readings whenever possible) for vertical angles. The booking for these secondary stations is almost the same as for theodolite, or « primary », stations; in fact, the three instruments mentioned above may be regarded as the component parts of a theodolite, carried separately for convenience. A plane-table is also carried.

The base line (at right angles to the main direction of measurement, for example, up a short valley) is measured directly, and arranged so as to intersect some distant prominent object which will give a clear mark for the box-sextant observation from each end. The level (which need not be telescopic, but which should have an extendible tube, slow-motion screw, and horizontal cross-wire) gives surprisingly good results if properly steadied. It may be stated as a general rule that « hand » instruments should never be held in the hand if it can possibly be avoided. The Author usually carried a light theodolite tripod for use as a rest. As the same problem has already been solved by camera-makers, the Author cannot claim originality for his suggestion, that portable survey instruments should be made to fasten in a similar way to some standard form of light collapsible tripod. Jacob's staffs are useless on rough or frozen ground, where their support is usually most needed.

Considerable use was made of a 20-inch « Surveyors' Slide-rule » manufactured by Messrs. Keuffel & Esser (New York), which reads to four significant figures, and may be used to obtain the principal trigonometrical functions of all angles with a probable error not exceeding 0.2 %

at any point. It also includes an ordinary and a stadia slide-rule, capable of the same degree of accuracy. In addition to its use for survey work, it almost obviates the use of tables for general civil engineering calculations. With this instrument astronomical calculations can be reduced in two or three movements, to the nearest minute of arc. The field observations are booked in the order in which they are read, so that any omissions show at a glance. Two sets of four observations each were usually taken at each determination of azimuth. The saving of work on this one item by the use of the 20-inch slide-rule is obvious. Although not so quick in operation as a solar attachment, it is a cheaper, more portable, and more universal instrument, and no less accurate in its results.

The instruments used for the first reconnaissance survey are precisely the same in principle as those mentioned in the two previous sections, with two important additions, namely, the aneroid barometer and the plane-table outfit.

Mention may be made of an interesting modification of the methods of this section, namely, the use of two theodolites, stationed a short distance (say 20 feet) apart, as a species of range-finder, to take the topography of places too steep and dangerous for staff-men to negotiate. One operator can easily attend to both instruments, reading them successively at each observation. The targets may consist either of weighted strings let down from above, and marked at regular intervals with bits of coloured cloth, or else of a spot of light projected from a mirror controlled by the observer, according to weather and other conditions.

Aneroid levelling.

Published experiences of surveyors differ widely on this subject, and the Author cannot avoid the conclusion that, after making allowance for varying human and climatic conditions, the aneroid

is a distinctly « temperamental » instrument. Of the Author's two aneroids, one had sustained some internal injury on the way out from England which rendered its movements inconsistent — too big when at rest, and too small when in the field, neither discrepancy being amenable to any discoverable law. The other was a first-class instrument, and in excellent order. As no mercury barometer was available, the aneroids were tested down a mine-shaft 600 feet deep, and gave results correct within 5 feet, or about 1 %. It was known that both barometers were wrongly set, but it was impossible to find out how much. However, the error from this cause was unlikely to exceed 0.25 inch of mercury (1 %), according to the barometric conversion tables. By chance or otherwise, the Author's results were in accordance with this estimate.

The weather conditions were very unfavourable for aneroid work. The air in North China is very dry in the spring, and changes of temperature and pressure are frequent and extreme, and also very local. Later in the year, when the weather becomes warm enough for rain, local thunderstorms take the place of dust-storms; even when these disturbances embrace both home and field aneroids in the course of their travels (which seldom happens at 100 miles' radius), there is always a time-lag of unknown extent. The Author's results might have been better had he had a mercury barometer at the home station. As it was, individual readings were often 50 feet out, but when time permitted taking a set of readings at one place, covering 2 or 3 days, the average of this set was within 1 % of the true value. Two sets of averages taken at Chao Yang and Hata (1400 feet higher) differed by about 15 feet, and their own average value differed from subsequent flying traverse levels by about the same figure.

The temperature-correction was al-

ways important, since the average outside temperature varied from 20° F. to 80° F. during the progress of the survey. It was taken in the usual way with a swinging thermometer. Home-station aneroid and thermometer readings were taken by a native clerk, at 2-hour intervals, between 7 a.m. and 5 p.m. daily. These records were forwarded at regular intervals to correct the field readings.

Unfortunately, during the progress of the second survey, in which the Author was able to check his readings directly against a fast line of ordinary levels, final results were spoiled by an accident to the field aneroid. Later elevations were, therefore, taken with an ordinary level.

The aneroid is an invaluable check on other methods of levelling, but it should never be relied on unaided, nor should it be expected to produce results beyond its capacity, and in order to produce the best results of which it is capable the average of a series of readings should be taken whenever possible, corrected in the usual way. The Author has not found a portable recording aneroid which fills the surveyor's requirements. The excellent little instruments of Messrs. Jules Richard & Co (Paris) have too close a scale for railway and allied survey work (though, on the other hand, the Author considers that instruments graduated to read single feet are a waste of money for this purpose). The continuous records of even an hour's readings taken (say) during a mid-day halt and corrected by a chart from the home station would give much better results than two or three isolated readings on a non-recording aneroid, corrected by a clerk's version of the home-station barometer reading, or (more likely) by an interpolation between two such figures. The average of 2 or 3 days' records at a main terminal station should be within 10 feet of the true figure at a 200-mile range, even in unsettled weather; probably a month's readings with a single instru-

ment, first at one station and then at the other, would produce nearly as good a result, though the Author has never had the opportunity of testing this. These advantages are largely lost with the present non-recording type of aneroid.

The Author believes that it should not prove impossible to satisfy the surveying engineer's requirements at a reasonable weight and price. Weight is, of course, important, because many aneroids perish by their own inertia during the shocks of transport in the field. This is probably why small aneroids are widely preferred to large ones, on the score of accuracy. In its present stage of development, barometric levelling in open country is seriously challenged even on reconnaissance survey by the latest forms of precise level.

Plane-tabling.

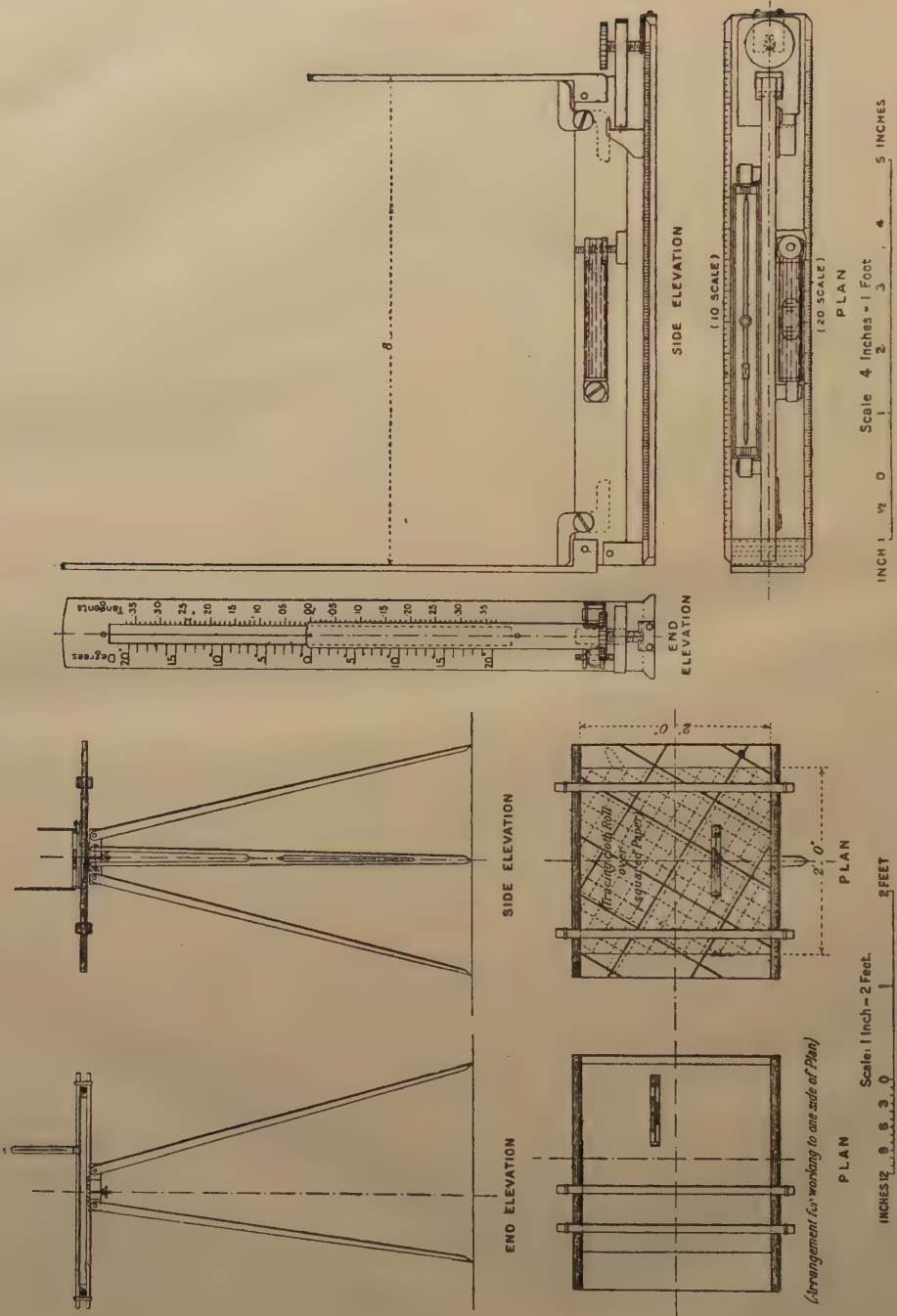
The plane-table was used to a considerable extent by the Author on subtense survey work, but not in the usually accepted manner. In his experience plane-table records are much inferior to notes of instrument work, because they are more perishable, harder to plot to different scales, and not susceptible to precise calculations (as for latitude and departure, etc.). He therefore uses the plane-table merely as a field drawing-table, to enable instrumental results to be plotted in the field (with stadia protractor, etc.), and also to assist in identifying mountain peaks, passes, and so forth, seen from a new angle. In other words, the plane-table is used on subtense survey to study work already done rather than to do the work itself. For this subsidiary purpose, it is invaluable; indeed for the pioneer in an unknown country, surrounded by unnamed mountains, without a map, it is essential.

The plane-table outfit used by the Author for his reconnaissance surveys consisted of a locally-made table 2 feet square, on which was permanently fast-

ened a sheet of squared paper. A roll of tracing-cloth, ruled for latitude and longitude by means of the graticule tables given in volume I of *Hints to Travellers*, was held in place over the squared paper by four wood battens, 3 feet long, two above and two below the table on each side of the centre, overlapping its edges by about 6 inches, and held in place by four adjustable elastic bands near the ends (fig. 8). Both the rolled and exposed portions of the tracing-cloth were securely held in place by these battens, even in windy weather; yet the elastic allowed of rolling and unrolling, or of moving the roll about on the table, as required. Although tracing-cloth does not keep true to scale, it stands the weather better than any kind of paper, and errors can be restricted to a single graticule by frequent astronomical checks. The squared paper takes the place of a tee-square, and points are plotted in the usual way with a semi-circular stadia protractor, having a 10- or 20-scale engraved on the straight edge, and the degrees figured in a counter-clockwise direction.

An Indian pattern clinometer was used to check results against the actual country. By adding to this clinometer a German-silver centre wire midway between the two scales, a zero-mark on the levelling screw, a small trough compass on the swinging arm, and 10- and 20-scales on the bevelled sides of the base, a « plane-table instrument » can be produced quite cheaply (fig. 9). In wet weather the plane-table was only used under cover and at night, but work went on just the same during the day by theodolite and portable instruments.

The Author's equipment included what may be termed a *portable* solar attachment, in the form of a Ferguson solar chronometer. This instrument provides an ingenious mechanical solution of the « astronomical triangle », and like the solar attachment, can be used to give time



and azimuth by the same operation. It can be set up and oriented (by its own indications, unaided by a magnetic compass) in 2 minutes, on any approximately level surface. The Author found that it would give local or standard mean time consistently within 1 minute of the correct value, and true north and south within 30 minutes of the correct value, if not used too near mid-day. Recently he carried out several successful plane-table surveys, using the solar chronometer as a true-north compass. While this method is free from the uncertainties attending the use of the magnetic compass to orient the plane-table, it is very dependent on the weather. Further, the short pendulum on which the setting of the instrument depends makes it impossible to use it in a wind. The difficulty met with in orienting the chronometer between the hours of 10 a.m. and 2 p.m. was overcome by setting a good watch to agree with it in the morning, and using this corrected time when the hour angle was too small for reliable readings from the unaided instrument.

All forms of sun-dial are « reversible » in this sense; that is, given the correct time, they can be used to find true north. In the form of « sun-compass » used by Commander Byrd on his recent flight over the North Pole (the invention of Mr. A. H. Bumstead, chief cartographer of the American National Geographic Society) both sun-dial and chronometer are combined in one instrument, making the correction for time automatic. The chronometer must of course be specially constructed to make only one revolution in 24 hours, in order to follow the apparent motion of the sun. But this instrument cannot (to the best of the Author's knowledge) check its own time, like the solar chronometer — that can only be done by using a point of shadow instead of a line, thus taking account of the sun's declination. Neither are its readings automatically corrected for the

equation of time. There seems to be no reason why the advantages of both types of instrument should not eventually be combined in a single portable « time-compass ». Meanwhile, considering the solar chronometer merely as a means of obtaining accurate (not precise) local mean time with the minimum of trouble and delay, it should be regarded not as a toy, but rather as a scientifically-designed instrument which no pioneer surveyor can afford to ignore.

Check-levelling.

The subtense method of survey, as developed in this paper, contains within itself a complete system of checks on the skeleton work of the traverse, so that gross or cumulative errors are almost impossible in main-station observations. However, neither instruments, operators, nor methods are perfect, so the Author has always employed a check-levelling party wherever possible, to supplement the theodolite levels. In flying traverse and first reconnaissance work the stadia wires, with which all modern levels are equipped, can also be employed to give a series of back and forward distances, which when integrated from a useful check on the subtense distances, assuming that the level party follows approximately the same route as the theodolite party. This method of working possesses the further advantage that it enables the level party to produce an immediate and accurate profile of the route, independent of the main party, thus helping to fix the limits within which a more detailed examination of the country is called for.

Two illustrations from the Author's experience may be cited. On one occasion during the course of a preliminary traverse survey in mid-winter, the delay usually caused by forcing pegs into frozen ground was obviated by giving this job to the check-levelling party, and allowing them to precede instead of follow

the main party. Thus the stadia party were provided with a set of stations carefully sited, spaced, pegged, and levelled by the advance party. Curiously enough this line of levels (run by a Chinese cadet engineer with a 14-inch dumpy level) served to expose a cumulative error of nearly 20 seconds per station in the alidade of the theodolite used by the Author for the stadia work of the same survey, which had not been detected in spite of the fact that reciprocal working was employed throughout.

On another occasion, whilst engaged on the first reconnaissance survey already described, the Author suspected the reliability of the aneroid barometers in use, and gave a Chinese student engineer the task of levelling 15 miles a day, in wet and windy weather, for ten consecutive days, using a Watts Zeiss-pattern level with quick-setting head, together with two staffs, and taking readings to the nearest 0.1 foot only; footplates were also provided, to prevent cumulative error in sandy and marshy ground. He successfully accomplished this task in the time prescribed, without noticeable error, and in addition recorded stadia distances for part of the journey.

Degrees of accuracy.

General principles. — Errors must be looked for in each of the three principal planes, which may be labelled (in defiance of scientific exactness) horizontal, vertical, and lateral respectively. In each of these planes errors may be propagated by successive observations; their effects may also transfer themselves from one plane to another during the course of a single observation. Errors (as opposed to mistakes) may roughly be classified as cumulative, compensating, and conditional. The first can usually be eliminated by reciprocal working or other means; the second and third cannot. All, however, are subject to fairly simple mathematical laws, whereby their prob-

able value for a single observation, and also their final value at the end of a series of observations, can be determined, with a degree of accuracy depending on the success achieved in eliminating « mistakes », that is, errors originating in the observer's mind and not inherent in the nature of the work. As a general rule, instrumental errors are cumulative, errors of observation compensating, and external errors conditional, in their effects.

Cumulative errors are usually measured by comparison with an independent instrument. They grow in direct proportion to the number of observations taken. Compensating errors can best be measured by repeated observations with the same instrument. The probable error of a single observation is, roughly, usually somewhat less than the « least count » of the instrument involved. Thus a fair angular value for a vernier theodolite is 15 seconds, or approximately 1 in 14 000. Compensating errors grow in direct proportion to the square root of the number of observations taken. Conditional errors, as their name implies, are the result of conditions external to the observer and his instrument, and consist of cumulative, compensating, and variable factors in different proportions according to their nature. A general expression for their rate of growth, including these three factors, would be $R = cm\sqrt{ms}$, where c is the « conditional » factor, m and \sqrt{m} the cumulative and compensating factors respectively for the m observations (out of a total of n) to which the particular error applies, and s the average value of the error for a single observation.

Figures 10 to 13 illustrate the application of the foregoing principles to the main sources of error in subtense survey, including their interaction between the horizontal and vertical planes. For simplicity, the diagrams refer mainly to stadia work; analogous results are work-

ed out later for the two faster forms of survey. Taking first the sources of horizontal error in the order shown, the stadia-wire error (present in most theodolites, to a greater or less degree) is purely cumulative, and can easily be eliminated by a percentage correction applied to each reading. The error caused by inaccurate staff readings is (like most observational errors) purely compensating, and its value is easily determined by the usual methods; it averages 0.2 % per station in careful work. The error due to inclination of the staff from the vertical position is a conditional one which may be described as a « variable compensating error », being dependent on the angle of slope between stations. A rough expression for its value is $s = 100 \gamma \tan \alpha$ per cent., where α is the angle of slope, and γ the angle of inclination. For the slopes usually met with in main-station work, this source of error can be neglected; however, if it is estimated to be appreciable for m stations of a traverse, the final probable error will be \sqrt{m} times its average value s . In this case, therefore, $c = 1/m$ in the general expression already given. These three horizontal errors q , r , and s give rise, as shown in figure 10, to three corresponding errors in the vertical plane, q_1 , r_1 , and s_1 , which must be combined later with the purely vertical errors q_2 , r_2 , and s_2 of figure 11, according to the law of least squares, to give the true values of the cumulative, compensating, and conditional errors acting in the vertical plane. As regards the vertical errors q_2 , r_2 , and s_2 , the zero error is a purely cumulative instrumental error which is easily eliminated by reciprocal working; though if preferred, it can be directly measured and then allowed for after its magnitude has been reduced as far as possible by careful adjustment of the instrument. The cumulative error due to eccentricity of the vertical circle can usually be neglected, even without

the precaution of reading both verniers at each observation; but this point should always be checked by direct comparison with precise levels. Errors in vertical circle readings are purely compensating, and average 15 seconds, or 0.008 % for vernier instruments; compared with these, the error made in observing the centre-wire staff reading is always negligible. Lastly, there is the « inclination error », whose value for a single observation (expressed like the others as a percentage of the horizontal distance) is roughly $s_2 = \gamma \tan \alpha$. The total conditional error in the vertical plane is therefore

$$\sqrt{s_1^2 + s_2^2} \text{ or } \gamma \tan \alpha \sqrt{(100 \tan \alpha)^2 + 1},$$

so that the horizontal error dominates except for very small values of α . If the stadia staffs used are equipped with properly adjusted spirit-levels, this source of error can safely be neglected for the small vertical angles met with on main-station work.

Another conditional error affecting the vertical plane is that due to the curvature of the earth (less a constant percentage for refraction), which approximately follows the equation, $y = 0.6x^2$, y being the error in feet (always in the sense of making objects appear too low), and x the length of the line of sight, in miles. The equation is of the form $R = m^2s$, to use the notation previously adopted, so that c in the general expression for conditional errors is here equal to \sqrt{m} . This error is easily eliminated by the use of balanced sights (another argument in favour of reciprocal working); but it should be borne in mind on reconnaissance, since it reaches considerable values at the distances there employed, and balancing at the same time becomes less perfect. For example, at 5 miles its value is 15 feet, which is greater than the average compensating error for the same distance. The general expressions

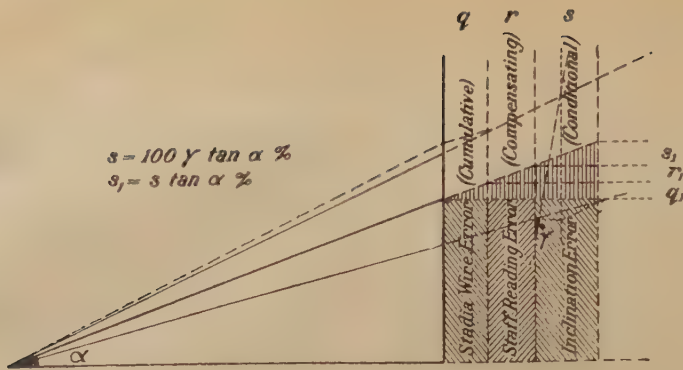


Fig. 10. — Horizontal errors.

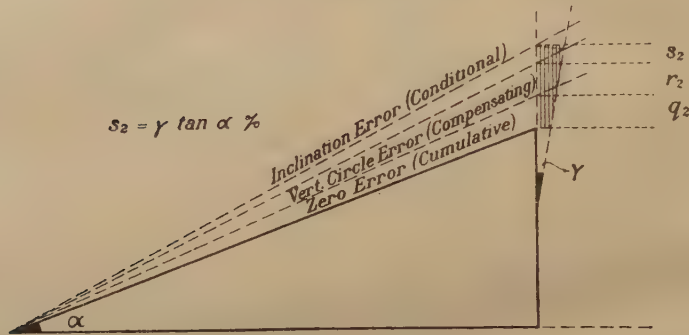


Fig. 11. — Vertical errors.

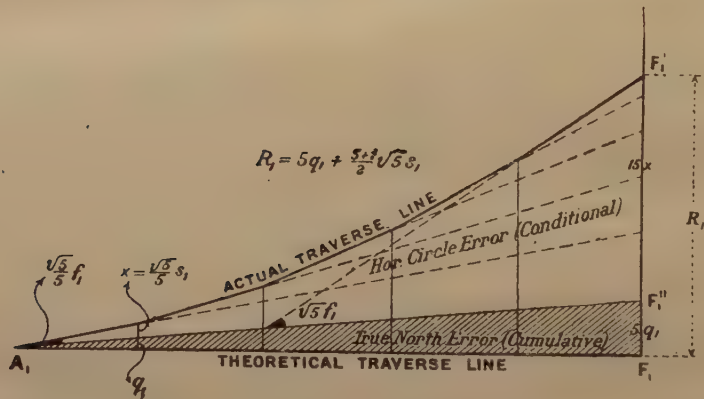


Fig. 12. — Lateral errors, deflection traverse.

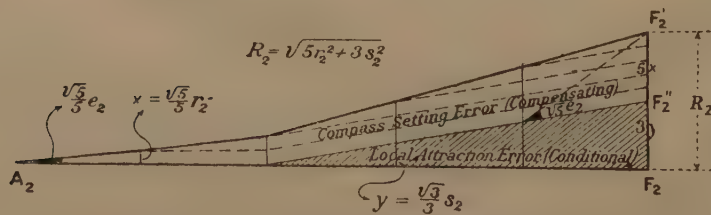


Fig. 13. — Lateral errors, compass traverse.

for horizontal and vertical errors finally reduce to the following forms,

$$R_h = nq \pm \sqrt{nr^2 + ms^2}$$

and

$$R_v = n(q_1 \pm q_2) \pm \sqrt{n(r_1^2 + r_2^2) + m(s_1^2 + s_2^2)}$$

using the same notation as before for the three classes of error.

Consider the first five legs of (say) a preliminary traverse survey, all assumed to be equal, and all in the same straight line, as shown by A_1F_1 in figure 12. Let the lateral error for a single observation, due to an angular error of f_1 minutes, be denoted by S_1 . As the angular errors are compensating, and their net effect is carried through to the last station by the deflection method of traversing employed, the final angular error at the fifth station will be $\sqrt{5}f_1$. Now in order to calculate the value of the resulting linear error, some assumption must be made as to the rate of propagation of this angular error. The simplest and most usual method (though not strictly correct) is to assume that it has accumulated by equal instalments of $\sqrt{5/5}f_1$ at each station, as shown by the curved line A_1F_1' in the diagram. The final lateral error $F_1'F_1''$ will then evidently be equal to

$$(5 + 4 + 3 + 2 + 1)\alpha,$$

$$\text{or } \{5+1\}5/2 \{ \sqrt{5/5} s_1 \}, \text{ or } \{5+1\}1/2 \{ \sqrt{5} s_1 \}.$$

In general

$$R = \{ (n+1) / 2 \} \sqrt{ns_1}$$

for a series of n observations, or (with sufficient accuracy for practical purposes)

$$R = \frac{1}{2} n \sqrt{ns_1}.$$

This particular type of conditional error, therefore, grows at a rate equal to that of an equivalent compensating error,

multiplied by a cumulative factor of $\frac{1}{2}n$:

it might fitly be described as a « semi-cumulative » error. In addition to this

conditional error, the deflection traverse is also subject to a small cumulative error (negligible in most cases) due to inaccurate determination of true north, and denoted on the diagram by q_1 ; the total error F_1F_1' due to q_1 and s_1 is

$$R_1 = 5q_1 + \frac{5}{2} \sqrt{5} s_1,$$

and in general

$$R_i = nq \pm \frac{1}{2} n \sqrt{ns}.$$

Evidently the diagram may be regarded as a plan of the survey (to an exaggerated lateral scale) in which the straight line A_1F_1 represents the traverse as it ought to be, and the curved line A_1F_1' the traverse as actually carried out under the influence of the errors q_1 and s_1 . It should be mentioned here that a more rigorous analysis of this problem leads to a slightly larger value for the final conditional error, namely,

$$(1/\sqrt{3}) n \sqrt{ns};$$

on the other hand, the approximate method of treatment adopted above lends itself more readily to diagrammatic illustration, while affording a result which is amply accurate for most kinds of engineering survey.

As a contrast to the deflection traverse, consider now the case of a free compass traverse, such as that employed in first reconnaissance survey, illustrated in figure 13. Here the error due to local variations in magnetic declination, corresponding to the cumulative error of figure 12, is the conditional one, whereas the ordinary lateral error is now purely compensating, since the traverse bearing is referred directly to magnetic north at every station. As it is impossible to

deduce any exact expression for the conditional error, owing to the fact that the « conditional » or fortuitous element predominates, it will be expressed instead as an equivalent compensating error; in the diagram it is shown acting on the last three stations, making the expression for the total error

$$F_2F_2', R_2 = \sqrt{5r_2^2 + 3s_2^2}.$$

In the general case, therefore,

$$R_l = \sqrt{nr^2 + ms^2},$$

where m represents the number of stations at which local attraction is likely to occur, and s its estimated average value. The greater the number of checks, the smaller this factor will be, and the more accurately it can be estimated and localized. In pioneer survey, on the other hand, the best that can be done is to combine both errors into a single compensating error, whose value is based on previous experience or on the results of the actual work in hand. With a trough compass the compensating error of setting (about 5 minutes) is usually negligible in comparison with the conditional error, especially in hilly country.

Another conditional lateral error to which deflection traverses are subject is that due to convergence of meridians, which at latitude 42° approximately follows the curve $y = 0.6x^2$, where y is the lateral error in feet after x miles, for an east-and-west traverse. For any other survey, y represents the error in latitude for a total departure of x , assuming it to be plotted by rectangular co-ordinates in the usual way. This is another example of a conditional error which increases as the square of the distance, a rate which soon leaves even cumulative errors behind. In spite of this rapid increase, however, it need only be taken into account if it is required to fit the rectangular co-ordinate system into the terrestrial framework of latitude and longitude. This is best done graphically,

by superimposing one on the other in sections, so that as far as the present discussion is concerned, the error due to convergence can be neglected; its mention here is necessary, however, in order to complete the general review of the more important errors affecting subtense survey which the Author has attempted. It is, of course, automatically eliminated in free-compass traverses such as those used on reconnaissance.

As regards the correlation of errors between the different planes, owing to the different rate of growth of each class, the only fair comparison is between their maximum permissible values; and the most obvious criterion for the latter is the smallest appreciable discrepancy on paper, or (say) a constant value of 0.03 inch translated into the scale appropriate to each type of survey. This does not mean to imply that anything can be done immediately to prevent errors from exceeding their maximum permissible value on the plan; but sooner or later a more precise survey will follow, as in the case of paper and field location, and if it is then desired to correct the former to agree with the latter, the above figure determines the stages by which this readjustment will be made. Taking first the correlation of horizontal and vertical errors, it is difficult to find an exact criterion to cover all cases; but if, as seems most obvious, the general grade of the country is taken as a suitable measure of their relative maximum permissible values, then subtense survey methods will be found to conform automatically to this standard, in most instances, owing to the fact that the portion of the vertical error which is derived from the horizontal error (always in proportion to the slope between stations) usually dominates all other sources within practical working limits. For the correlation between horizontal and lateral errors, since these are really only the com-

ponents of a resultant « traverse error » by which the general accuracy of a traverse survey is usually expressed, equality at maximum permissible values should be the ideal standard, and rough equivalence the practical criterion, for their correlation.

Before proceeding to apply the general results outlined above to the three classes of survey described in this paper, it may assist matters to recognize four main degrees of accuracy, covering the requirements of various stages of railway survey work, namely, rough, approximate, accurate, and precise, corresponding to probable horizontal errors

falling between the limits of $\frac{1}{10}$, $\frac{1}{50}$, $\frac{1}{250}$, $\frac{1}{1250}$, and $\frac{1}{6500}$, or 10, 2, 0.4, 0.08, and 0.016 % respectively. The surveys already described fall (as far as main-station work is concerned) within the categories of accurate, approximate, and rough according to this (admittedly arbitrary) rule, for which the Author's only excuse is that he has found it to be of practical assistance in his own work. Location survey, which falls within the remaining category, is outside the scope of this paper, though referred to briefly in connection with paper location methods. As regards the relation between main station and subsidiary observations, the requirements of railway work are best satisfied when topographical work falls within the limits of the next lower degree of accuracy (if any) to that of the main traverse on which it depends; thus it need never exceed the limits of approximation, or say 0.5 % on preliminary work, and, on the other hand, errors up to 10 % can be tolerated (but not encouraged or exceeded) on reconnaissance. If this ratio between skeleton and detail errors is accepted as a rough criterion, it follows that nothing is ever gained in traverse work by numerous repetitions of main-station ob-

servations in order to reduce their probable error, as practised in triangulation survey; for the same effect is better arrived at by shortening the distance between stations, thus enabling every process to share in the benefit, and preserving the pre-arranged balance between them. If the vertex angle of the « distance » triangle is kept always within the established limits of $\frac{1}{50}$ and $\frac{1}{200}$ the proper correlation between all the various parts of subtense survey work can easily be maintained without recourse to repetitions.

Practical applications. — The issue has now been reduced to the interaction of nine fundamental elements, namely, three main classes of error acting in the three principal planes, on three representative types of subtense survey. For simplicity, only main-station working will be considered, the same average vertical angle will be taken in each case, and all errors will be expressed as percentages of the average distance between main stations. Fortunately it is possible to ignore most of the permutations and combinations of the nine elements just mentioned, only retaining a few whose magnitude demands attention. The simplified problem may be stated as follows: as regards the first or « distance » triangle of subtense survey, the main sources of error lie in the wrong estimation or measurement of base and vertex angle; as regards the second, or « altitude » triangle, in the wrong measurement of the vertical angle, coupled with the use of an incorrect base distance (through propagation of the distance error of the first triangle); to these must be added the lateral errors introduced by wrong measurement of azimuth. All the above errors, except the conditional lateral error caused by the use of deflection methods of traversing, are compensating; cumu-

lative errors, together with all other compensating and conditional errors, are assumed to be eliminated, allowed for separately, or neglected altogether. These simplified conditions are illustrated in figures 14, 15 and 16 for preliminary traverse, flying traverse, and first reconnaissance survey respectively. The average slope for main-station work has been assumed to be 1 in 50, a value taken from the Author's field books, in order to facilitate comparison with his own results; as the vertical component of the horizontal error varies in direct proportion to the vertical angle itself, it is easy to combine this with the same or some other vertical circle error, to obtain the figure for any particular case. The total vertical error is simply the square root of the sum of the squares of its two component parts, according to the usual rule for the addition of compensating errors. Similarly, as regards the distance triangle, the horizontal error varies in inverse proportion to the vertex angle; 1 in 100 has been taken as a typical value for the latter, but in practice it varies between 1 in 50 and 1 in 200 for the two faster kinds of survey. In figures 14 and 15, the values of the three main errors have been based on the figures already suggested for the probable staff and angular errors of a single observation, namely, 0.2 and 0.008 % respectively; in figure 16, the figures are mainly deduced from the results of the Author's experience, on the assumption that all three are compensating in their effect, a point which has already been discussed in connection with the lateral compass error. No direct account has been taken of the effect of reciprocal working in reducing horizontal and vertical errors by duplicating the readings for each quantity. Strictly speaking, its effect should be to reduce these errors to $\sqrt{2/2}$ or, roughly, three-quarters of the values given in figures 14 to 16; but the Author prefers to regard it as a « factor

of safety » to be balanced against those malign influences which lie between errors and mistakes.

Turning to the actual figures for horizontal errors, the first, namely, 0.2 %, has been chosen as a compromise between the quantities given by various authorities for stadia survey; it expresses the normal limits of human vision, aided by a telescope of average power, in reading the staff at (say) 500 feet. The second, 0.5 %, is simply the ratio of the probable angular error to the average vertex angle, that is, of 0.008 to $\frac{50}{3\,000}$ (or 0.17). At first sight it might appear that a 100-foot base would increase both the scope and accuracy of this form of traverse. This may be true in fairly flat country, where obstacles are few and topography easy; but in hilly country it will be found that the errors of orientation and measurement of the longer base (negligible at 50 feet) often rise to a value where they neutralize the added accuracy due to its length, while the extra time occupied in setting it out on broken ground more than offsets any gain due to longer station-intervals. The latter are really governed, as remarked before, by topographical requirements; and, if the method adopted is sufficiently accurate for the station-intervals imposed by the topography of the country, further justification for its use is hardly needed. The third, namely, 2.5 %, is an empirical figure summing up the indirect influence of the compass error, and the effect of size and shape of target, into one equivalent compensating error; the effects of angular errors (assuming that readings are taken to fractions of a minute) can be neglected, by comparison, for vertex angles within the accepted limits of 1 in 50 and 1 in 200. Staff-reading errors in measuring length of base by stadia methods are, of course, also negligible in comparison with a quantity about ten times their size, so

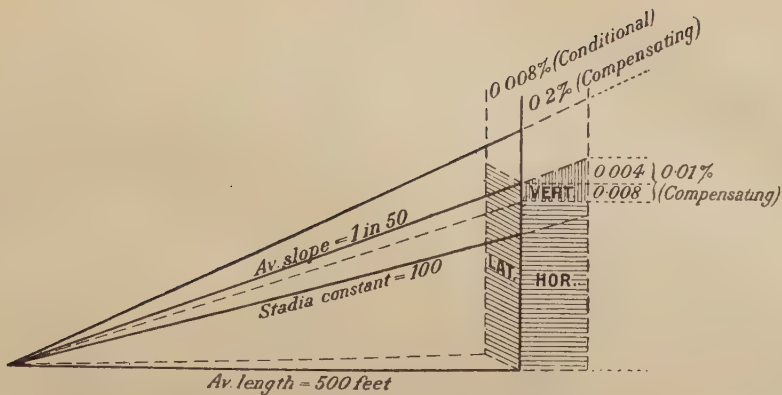


Fig. 14. — Preliminary traverse (accurate).

Average scale : 1 inch = 400 feet.

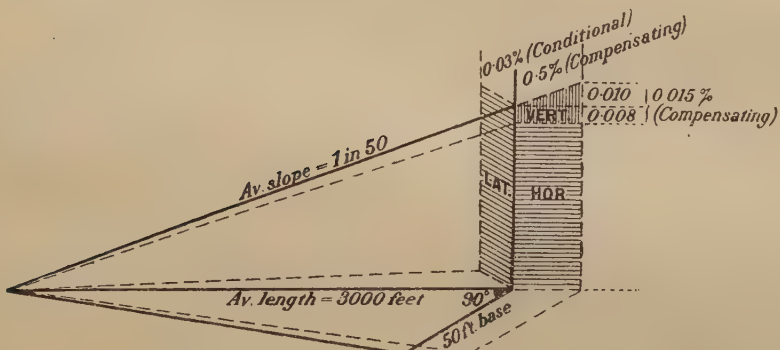


Fig. 15. — Flying traverse (approximate).

Average scale : 1 inch = 2 000 feet.

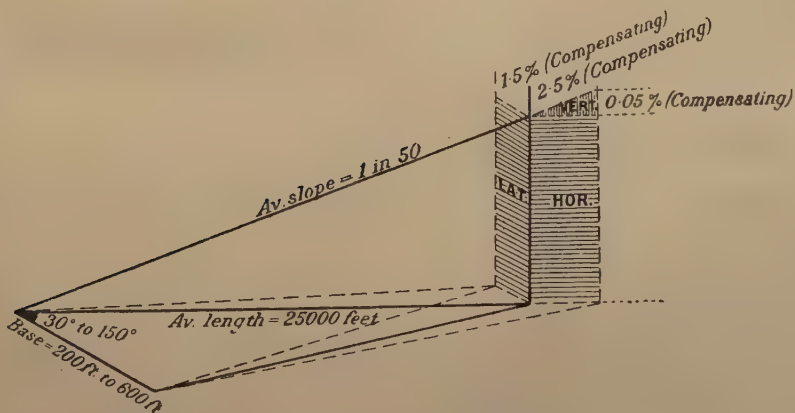


Fig. 16. — First reconnaissance (rough).

Average scale : 1 inch = 10 000 feet.

that this unorthodox but expeditious means of measuring base lines can be adopted on reconnaissance without fear of its affecting the quality of the work in any way.

As regards the vertical errors, the first and second are compounded of a constant vertical circle error of 0.008 %, and indirect horizontal errors of 0.2/50 and 0.5/50, or 0.004 % and 0.010 % respectively. The resulting errors are approximately 0.01 % and 0.015 % of the horizontal distance. The third error simply consists of the vertical component of the horizontal error, since the angular error no longer counts; its value is 2.5/50 or 0.05 %. At an average distance of 5 miles between stations, the last error would amount to 50 feet in 80 miles in the worst case, that is, only sighting a single peak from each station. This is not as good as the result produced by even moderately good aneroid levelling; on the other hand, it is probably more reliable, and certainly quite accurate enough for the purposes of reconnaissance survey. If any particular locality obviously demands greater accuracy, a fast line of levels, or alternatively a flying traverse survey (with a vertical error of only 5 feet in the same distance), will soon solve this local problem, and its results can afterwards be fitted into the general framework of the reconnaissance survey plan, making due allowance for the error caused by convergence of meridians.

Finally, as regards lateral errors : the first is simply the value already assumed for the probable angular error, namely, 0.008 %; the second, which represents an average error of about 12 inches in setting up over each station, due to lack of permanent pegs on which to plumb the instrument, is an empirical figure embodying the results of the Author's experience in this type of survey. It allows an ample margin for any inaccuracy likely to arise through setting up without the use of the plumb-bob. Pro-

vided all main-station bearings are read to fractions of a minute, their angular errors can be neglected in comparison with the above error of roughly 1 minute, or 0.03 %. As both these lateral errors are « semi-cumulative » in their nature, their correlation with the horizontal errors can only be tested for their maximum permissible values, namely, $\frac{400}{30}$ feet and $\frac{2\,000}{30}$ feet, or (say) 15 feet and 65 feet, respectively, according to the rule given in the previous subsection. From the equations

$$R_h = nr, \text{ and } R_l = \frac{1}{2} n \sqrt{ns},$$

the following values are derived : for the first case, $R_h = 10$ feet and $R_l = 20$ feet after one hundred stations, or (say) 10 miles; for the second, $R_h = 75$ feet and $R_l = 55$ feet after twenty-five stations, or roughly 15 miles. These figures indicate a satisfactory correlation according to the criterion of rough equivalence at the lowest appreciable value

on paper, namely, $\frac{1}{30}$ inch measured at scales of 400 feet to 1 inch and 2 000 feet to 1 inch respectively. To revert to the individual lateral errors themselves, the third, representing a free compass error of 1.5 %, is an empirical value equivalent to the average effect of local magnetic attraction, expressed as a compensating error of 3/4 degree per station throughout. This figure is by no means excessive for rough country, even assuming a reasonable number of astronomic checks, seeing the compass often varies a degree or more in rounding a single hill; as it rarely exceeds the horizontal error, however, it need not be considered serious. The final relation between the lateral and horizontal errors is really determined, not by the figures themselves, but by the general direction of the traverse, as the latitude correction always prevents any appreciable accumulation of errors

in a northerly or southerly direction. For this reason it is better to compound the two into a compensating « traverse error », which gives a truer comparison between different results; it should not normally exceed one mile on a traverse of fifty stations, or (say) of 250 miles in length, given reasonable conditions. As the « traverse error » of a single observation is liable to exceed the previously defined « maximum permissible value », the whole method would seem to stand condemned by this rule. As a matter of fact, it is condemned from the very first, being in reality only a preliminary manoeuvre in order to discover a location which warrants the making of an accurate (or at least an approximate) plan. In other words, the term « rough » cannot be admitted as a permanent label for any engineering undertaking.

As a further application of the diagrams under discussion (and a final word on the subject of errors), mention might be made here of the correlation of errors in subsidiary shots for topographical detail on preliminary work. Having decided that an accuracy of one-fifth of that of main-station working still

left ample margin for topographical purposes, the Author felt justified in using ordinary ranging-rods in lieu of stadia staffs for the latter, in the manner already explained. An examination of the other processes involved in taking spot levels showed that two further simplifications could be introduced without altering the quality of the work, namely, the reading of angles only to the nearest minute, and the sighting of a constant height of 5 feet on the rod; instead of the exact height of instrument; for none of the errors involved exceeded those directly due to the use of the ranging-rod as a staff. Thus the increase in speed and mobility made possible by these innovations was secured without loss of either utility or balance, by a simple application of the principles established at the beginning of this section. While it is evident that too much reliance must not be placed on theoretical calculations based on assumptions which themselves are only imperfectly realized in practice, it is a great gain to have the tendencies and limits of related operations brought, however roughly, within the scope of judgment and forecast.

Notes on railway survey, ⁽¹⁾

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The following notes have special reference to conditions in India, and cover a number of points with which the Author had recently to deal, both in the field and in recess preparing estimates, during three seasons spent on surveys for the project known as the Central Indian Coalfields Railway.

Reconnaissance.

Reconnaissance of the nature about to be described is an essential preliminary to the proper conduct of a detailed survey. A railway is constructed to serve one or more definite purposes such as, for example, the development of an area, or as a chord line, or for strategic purposes, and this intended traffic must be kept in the forefront of any preliminary consideration of a projected line. Such consideration must at the start be on the broadest and most general lines, detailed estimates of weights of particular commodities, etc., if required, being left to a later stage of the survey; and the traffic reconnaissance should deal with the probable trend and development of traffic for the projected line in the same wide spirit as is laid down by text-books for the engineering reconnaissance. The latter, of course, must be of an area and not of a line. Consideration must be given throughout to the results of the parallel traffic reconnaissance, and the conclusions of both are interwoven and interdependent. In easy country traffic considerations reign almost supreme, while as the country grows more diffi-

cult the requirements of the engineer become increasingly weighty, up to the point where the physical possibility of a line of the nature required, at any reasonable cost in relation to the expected traffic, becomes the limiting factor.

The reconnaissance survey in both its aspects depends, in its scope and in the work involved, upon the nature and state of development of the country concerned. With easy, well-known and well-mapped country, all the information required for the reconnaissance may perhaps be obtained in a few days from existing maps, reports, and statistics, and by comparison with other areas or lines of which the development and traffic requirements are known, without any other extensive examination of the actual area concerned, either physically or in respect of the traffic likely to be met. Difficult, undeveloped, or badly-mapped country needs more or less thorough investigation on the ground in addition, which may, in the extreme case, require a whole season's work.

These notes, however, are not so much concerned with the difficulties and conduct of the reconnaissance, as with its results, which must be on record in some form or other before a detailed survey can be carried out to best advantage. The record may be of the briefest nature, but in essence it must give information on the following lines for the benefit of the engineer who is to carry out the detailed survey.

From the traffic point of view, an ap-

(1) Abstract of Selected Engineering Paper No. 54, published by the *Institution of Civil Engineers*, London, 1927.

proximate estimate should be given of the probable nature, tonnage, origin or destination, and directions, of the expected traffic, reduced in the simplest case to the number and kind of trains each day in each direction. Special note should be made of any traffic foci, and of any expected future developments which may have to be allowed for.

On the engineering side, after taking the above considerations into account the reconnaissance should decide the general route to be followed, having in view, in addition to traffic requirements, such engineering matters as controlling points for the passage of hills and rivers, the general roughness or easiness of any particular portions of the area, and points such as the supply of water or building materials, or the like, as far as they weigh in affecting a choice of route. Frequently reconnaissance can only suggest alternatives, leaving it to a more detailed survey to decide which of these is to be preferred, but this will not in general alter the information on the above lines, which ought to be collected before any detailed survey is begun.

In addition, it is also desirable that the reconnaissance summary, whether prepared in the office, or after investigation in the field, should also deal with the following questions.

Gradients. — The ruling gradients in each direction must suit both the expected traffic and the country to be traversed; and in fixing them due regard must be paid to the very considerable operating savings made possible by carrying the traffic in fewer and heavier trains over flatter gradients, a point illustrated by the appendix. In this connection the question of pusher gradients (or banking sections) often arises, where a flat general ruling gradient is used in conjunction with a steep one over a short section, up which a standard train is hauled by two or more engines. The introduction of a length of

such special steep gradient in a difficult section of country can often be justified on theoretical grounds of cost of construction and working, but there are many operating objections to banking, especially where the banking gradient is much steeper than about 1.0 %, when as many difficulties occur in the descent of long heavy trains in connection with braking, shunting at stations, etc., as in the ascent itself. It is hardly possible to express these in terms of money, but they should be given full weight when any proposal for banking is under consideration.

Curves. — The limit of curvature is frequently based on some outside consideration such as the design of engines and rolling stock, but regard should be had to the speed and nature of the expected traffic, and especially to the character of the country. In difficult or hilly country a slightly sharper limit of curvature often allows large savings to be made in capital cost. For instance, on one section of the projected Central Indian Coalfields Railway, over which 5-degree curves were used, any flatter curvature would have entailed a quite prohibitively costly line.

Stations, etc. — The distances at which stations are to be spaced, the lengths of station-yards of various classes, and the standards of special flat grading for them, should also be noted. The effect of flat grading at stations is very considerable in country involving much change of level, and must be taken into account at the time of reconnaissance in determining what ruling gradient can be used. The approximate siting of engine-changing stations and of any district or similar railway headquarters is also a matter which should be mentioned in the reconnaissance summary.

All the above are items in which questions of general and operating policy, which usually affect a wider area and a

much greater length of line than that immediately under consideration, must prevail over such purely local factors as would frequently attract the attention of the engineer in charge of the detailed survey.

Costs. — Any possible information about the available transport, labour-supply, natural resources, etc., of the area should be given, which can assist the engineer in charge in obtaining, before starting the detailed survey, rough ideas of probable construction-costs, for use in the field as described later.

Negative information is frequently of great value: the fact that a given route has been definitely ruled out as unsuitable (reasons for this being given), or that the traffic from a particular source is, in the general circumstances, not worth considering, may be very useful to a locating engineer. Mention should be made of any expected or possible difficulty with materials or labour, which will ensure that such point is fully considered in the detailed survey.

Office preliminaries to detailed survey.

The reconnaissance survey having been completed, a number of matters remain which ought to receive consideration before any field work is started. In the Author's recent experience many of these points were only fully dealt with in the recess after the first season's work, which fortunately was reconnaissance and preliminary survey, without any final line being set out. When in a later season, this route was finally staked out, several quite important changes from the first season's « paperline » were found desirable, as a result of systematic consideration of the points now to be detailed. Some of these may already have been touched upon in the reconnaissance summary, but they are included here to ensure their consideration.

They relate to two main heads: 1. Ap-

proximate relative costs of both constructing the line and operating it for the expected traffic, for various construction alternatives; 2. Standards and types of various kinds, which must be determined more or less definitely before a survey party can usefully locate or provide for the works to best advantage in the field.

Under the first head are:

A. — Relative operating-costs of different ruling gradients, and other data relating to grading.

B. — Operating-cost of small changes of length of line.

C. — Operating-cost of rise and fall.

D. — Operating-cost of curvature.

E. — Maintenance- and depreciation-costs of different classes of works.

F. — Construction-cost, per chain of line, of earthwork for different heights of bank and cutting, in the various soils likely to be met with.

G. — Construction-cost, for different heights of formation above bed, of the various types of bridges and culverts to be used.

H. — Cost of tunnels and high viaducts, when likely to be needed.

I. — Cost of track and of ballast per mile.

With the foregoing information at his disposal, the engineer in charge of a party in the field is in a position rapidly to compare the approximate costs of both construction and operation of alternative alignments which may present themselves, and he can assess the relative values of any savings or increases of length, curvature, etc., against the increased or reduced construction-cost resulting from them. These sub-heads are dealt with in more detail later.

Under the second main head of standards and types come:

J. — Ruling gradients to be used, and standards for vertical curvature.

K. — Limit of curvature, compensation for curvature in grading, and standards for transition-curves and for reverse-curves.

L. — Lengths of, and special grading for, station-yards.

M. — Approximate distances to be allowed between station-sites and between watering-stations.

N. — Standard types of bridges and culverts to be used.

O. — Approximate types of various classes of stations in sufficient detail to enable suitable sites to be surveyed and selected.

P. Approximate positions, or distances apart, of any special quarters required, such as open-line or construction headquarters, quarters for inspectors, etc., so that suitable land may be surveyed and selected.

Q. — Classes of level crossing to be provided, so that the appropriate types can be selected and noted in the field for each crossing required.

R. — Approximate daily requirements of water at watering and engine-changing stations.

S. — Orders as to provision, if any, for future doubling.

In general, the information provided should be sufficient to enable the engineer in the field to deal, during the whole time he is locating, with the actual gradients, curves, bridges, stations, and works generally that he will have to estimate for when preparing his working plans. Stress is laid here on this point, for it has been the Authors' experience several times both to feel in the field the need for some such item of information for the proper consideration of the location and also — especially — to find during the recess that some point required to be drawn out and estimated for cannot be dealt with adequately in the office alone. It is very important that as far as possible the project should be complete, with all the necessary work-

ing details duly considered, so that when orders for construction are sent out, working parties can start on land-acquisition, etc., at once, without wasting time over re-alignments and other alterations in detail, which, while they may not greatly affect the estimated total cost of construction, do frequently cause great delay at the start and in the progress of active construction work.

It is impossible to lay down universal figures or standards for even a few of the foregoing items, but examples will now be given of some of the data worked to for the Central Indian Coalfields Railway project.

A. — *Data relating to gradients.* — As the Central Indian Coalfields Railway was to be designed to carry a heavy mineral-traffic, the easiest ruling gradient that would suit the country was obviously desirable, and 1 in 200 was selected. The experience of the neighbouring East Indian and Bengal-Nagpur Railways showed that this is the steepest desirable gradient for heavy traffic, but, while 1 in 200 gave a reasonably direct line over the long climbs necessary up to controlling summits, no lighter gradient could be fitted to the country traversed, which was not suitable for development to obtain flatter grading.

The operating-costs of the 1-in-200 gradient may be based on figures of the regular performance of trains on it, *e. g.*, that a heavy goods-engine weighing 110 tons can regularly haul trains of 1 650 tons gross behind the tender. Such trains, if fully loaded, would consist of about fifty-two four-wheeled vehicles, of 5-ft. 6-in. gauge, carrying 1 150 tons load against a tare of about 500 tons.

The appendix gives an estimation, based upon the above data, of the annual cost involved in the substitution of 1 in 100 for 1 in 200 as the ruling gradient of a line. And (under assumed conditions regarding working-costs), the figures there adduced show that, unless distance

can be materially shortened by the change, no saving of construction-cost per mile reasonably likely as a consequence of the use of the steeper gradient can compensate for its higher working-cost, except where the traffic is of the lightest nature.

The first question that arose, however, with the Central Indian Coalfields Railway was that of pusher gradients. As stated previously, there are many objections other than the mere extra cost of increased engine-mileage to be set against the use of steep pusher gradients, and there would seem to be almost a consensus of opinion among operating men that their use cannot practically be justified on lines with more than a very few trains per diem, in circumstances where there is a practicable way of avoiding them. No comparisons, therefore, of the relative operating-costs of pusher and of ordinary gradients are given by the Author.

In some cases, however, as on one section of the Central Indian Coalfields Railway project, the use of pusher gradients is inevitable if a light ruling gradient is to be adhered to elsewhere, and it is necessary to know what gradient exactly is the equivalent of the ordinary ruling gradient concerned. The treatment of the subject ⁽¹⁾ by the late Mr. A. M. Wellington, M. Inst. C. E., is much affected by the figure taken for train-resistance on a level track, namely, 8 lb. per (short) ton, equal to 8.96 lb. per English ton; but he stated that this might be 2 to 4 lb. too high for low speeds. Mr. C. A. Carus-Wilson gave ⁽²⁾ the resistance, measured by dynamometer-car, of a four-wheeled Bengal-Nagpur Railway wagon loaded with 22 1/4 tons of coal as 6.7 lb. per ton at 25 miles per hour.

⁽¹⁾ *The Economic Theory of Railway Location*, New York and London, 1903.

⁽²⁾ *Minutes of Proceedings, Institution of Civil Engineers*, vol. CLXXI (1908), p. 252.

An assumed resistance of 6 lb. per ton accords with the foregoing figures and gives results on the right side in the calculation of the equivalent gradient.

Using the data previously given for weight of train and engine, and assuming the assisting engine to be of similar weight and boiler-power to the train engine, this calculation is as follows for a ruling gradient of 1 in 200.

The continuous effective force exerted by one engine when hauling itself and a 1 650-ton train up a gradient of 1 in 200 (neglecting the internal resistance of the locomotive, which does not affect the problem) is $(1\ 650 + 110)$ tons $\times (11.2 + 6)$ lb. per ton = 30 270 lb.

Two similar engines can, therefore, exert twice this, = 60 540 lb., and if r lb. per ton is the resistance due to the equivalent pusher gradient, then $(1\ 650 + 220)$ tons $\times (r + 6)$ lb. per ton = 60 540 lb., whence $r = 26.4$ lb. per ton, equivalent to a gradient of 1.18 %.

Mr. Wellington, using a resistance figure of 8.96 lb. per ton, gave a calculated equivalent gradient of 1.30 % with his conditions, instead of the above, but he laid stress on the desirability of not working fully up to the figure theoretically obtained, and suggested a reduction in practice of 0.1 to 0.2 %. The gradient of 1.18 % arrived at above was therefore reduced to 1.1 % as the accepted pusher gradient for the Central Indian Coalfields Railway project, corresponding to the ruling gradient of 0.5 %.

It was found that very considerable economies in length and construction-cost would result from the use of a gradient slightly steeper than the standard 1 in 200, in places where the gradient would be against the direction of traffic of empty mineral-trucks returning to the coal-field. In the case in point, a gradient of 0.55 % sufficed to deal with the situation, and the following calculation (which uses the same data as before) shows what proportion of the normal

train would have to consist of empty vehicles on such a gradient.

Let n be the fraction of the train fully loaded, then $1\,650n$ tons is the weight of the loaded vehicles, assumed to have a resistance on the level of 6 lb. per ton; and $500(1 - n)$ tons is the tare of the empties, of which the tractive resistance is higher, say 8 lb. per ton. The resistance due to the gradient is 12.3 lb. per ton, and this must be added to the above figures. Then

$$30\,270 \text{ lb.} = (110 + 1\,650n) \times 18.3 \text{ lb.} + 500(1 - n) \times 20.3 \text{ lb.}$$

for locomotive and loaded portion, and empty portion of the train respectively; whence $n = 0.90$, equivalent to less than six vehicles running empty in each normal train of fifty-two, a state of affairs well within the probabilities of the case.

Elsewhere, on a section where a considerable difference between east-bound and west-bound traffic seemed certain, the ruling gradient for the former was made 1 in 150 against 1 in 200 for the latter; for this on a similar calculation n works out at 0.72, equal to about fifteen vehicles empty out of every fifty-two.

B, C, and D. — *Operating-costs of small changes of length, of rise and fall, and of curvature.* — Table I was worked out on the lines followed by Mr. George Richards, M. Inst. C. E. ⁽¹⁾. Modern opinion seems perhaps to doubt the accuracy of results thus obtained by applying Mr. Wellington's methods of analysis, but these figures at least give guidance in dealing with the question, and they bring out approximately the relative importance of the three factors. It is hardly practicable to go so fully into relative construction-costs that these particular results can be taken into account down to the last rupee.

⁽¹⁾ *Indian Railway Board Technical Paper No. 197*, which deals with these figures for metre-gauge railways in Burma.

The above data are subject to the important proviso that earnings are not affected by the changes of length. This will not strictly be the case in all circumstances, but with Indian conditions of railways mainly owned by the State, any increase of earnings due merely to longer length is in effect an indirect tax on trade and tends to restrict traffic, and *vice versa*; and it is usually expedient in this connection to assume that earnings are unaffected by such small changes.

In considering the capitalized value of savings in length, to be offset against increased construction-cost, or *vice versa*, it is convenient to add to the figures in column 4 for the first three lines of table I the fixed cost of track and ballast per foot or per mile, which are figures independent of the number of trains. For the Central Indian Coalfields Railway project these were 10.6 rupees per foot, or 56 000 rupees per mile. Then with six daily trains in each direction a small saving of length under line 1 of the table equals 20.4 rupees per foot saved; add 10.6 rupees for track, and the total figure of 31.0 rupees per foot is a measure of the value of the saving to be set against the cost of more expensive works in the shorter alternative.

E. — *Maintenance- and depreciation-costs of different classes of works.* — In dealing with the approximate costs of works, which are to follow, account must be taken of the additional annual expenditure on account of repairs and depreciation which will have to be incurred if heavier works are necessitated by any alternative alignment, and the Author suggests dealing with the question on the following lines.

The total annual expenditure on repairs and depreciation for each class of work (for example, earthwork, masonry structures, steelwork) may roughly be expressed as a percentage p of the capital cost C of that class of work. If r is the assumed current rate of interest,

as in table I, the extra annual expenditure necessary for repairs and depreciation virtually increases the capital cost for that class of work by Cp/r .

TABLE I.

Capitalized effect of small changes of length, of rise and fall, and of curvature, per daily train in each direction. For 5-ft. 6-in. gauge, based on the Bengal-Nagpur Railway figures for 1921-1922.

ITEMS.	Approximate annual cost.	Annual cost capitalized at 5 per cent.	Capitalized cost per unit concerned.
1	2 Rupees.	3 Rupees.	4 Rupees.
1. Short changes per mile.	890	17 800	3.4 per foot.
2. Larger changes per mile	970	19 400	19 400 per mile.
3. Large changes affecting stations per mile . .	1 240	24 800	24 800 per mile.
4. Rise and fall, medium, per 26.4 feet.	142	2 840	107 per foot of rise.
5. Rise and fall, considerable, per 26.4 feet. . .	275	5 500	210 per foot of rise.
6. Curvature, per 600 degrees.	1 180	23 600	39 per degree.

The figure p will differ for various classes of work, being the sum of the percentages necessary for repairs proper and for the replacement of the item when it ceases to be repairable at the end of its useful life. For Indian conditions, the recent rules for fixed annual payments to a depreciation fund over fixed periods for different classes of wasting assets provide a measure for the latter fraction.

For the present consideration of the subject, works of which it will be necessary thus to compare the costs may be divided into three main classes of 1. earthwork, 2. masonry bridges, and 3. girderwork. As regards 1., no annual payment is made to the depreciation fund, and p consists merely of the annual cost of repairs. This may be taken at a figure not exceeding $1/4$ %, and if r is 5 %, then $C/20$ for earthwork must be added to the capital costs of the earthwork of each of two alternatives, to get a true comparison between them. For 2. masonry bridges, with an annual

payment to the depreciation fund of $1/125$ of their first cost, the share of p for depreciation becomes 0.8 %, while the annual cost of repairs may be taken as not more than 0.2 %, making p equal to 1.0 %. With r at 5 % a similar addition, therefore, of about 20 % must be made to the capital cost of masonry bridgework. For 3. girderwork, in addition to a share of p of 1.66 % corresponding to an annual payment to the depreciation fund of $1/60$ of the first cost, an allowance of about 0.6 % may be made for repairs, including painting, giving a total of about 2.3 % for the annual cost of repairs and depreciation, equivalent, under the same conditions as above, to an addition of about 46 % to C for girderwork.

Depreciation for permanent way has already been included in the maintenance expenditure involved by extra length of line, etc., in table I.

F. — Construction cost per chain of earthwork for the different types of soil

likely to be met with. — Only a rough classification of soils is possible, and table II was worked out for assumed conditions for the Central Indian Coalfields Railway project, where cuttings of any depth were likely to be in rock, more or less hard. Several facts are evident from the table, which are well seen when it is plotted as a series of curves.

1. Cutting, when rock occurs, is much more expensive than bank, and in such circumstances the line should be graded high. (The cost of bridging, in this connection, is dealt with later.)

2. The cost of low earthwork is relatively very unimportant, and small savings of height in low banks justify very little expenditure in other directions.

3. Where land is not abnormally expensive, or where rock is not met with so close to the surface as to hinder the excavation of borrow-pits, attempts at « balancing » banks and cuttings are not productive of important economy, except for quite short leads. Comparison between lines 1 and 2 and lines 9 and 10 of table II shows what a relatively small saving is effected by tipping the cuttings to bank with a moderate lead; and figures such as those of lines 1 and 2 may therefore be used without serious error, in the rough calculations in the field that these tables are intended to facilitate, for all banks, whether tipped or dug from borrow-pits.

The table does not include the cost of land, which would have to be allowed for in comparisons between various alternatives, if it were not cheap.

G. — *Construction-cost of bridges and culverts.* — For the Central Indian Coalfields Railway project types of arch (under-) bridges were selected and drawn for minimum heights of bank in each case, the designs being such that it was always cheaper with a small number of spans to lengthen the barrel than to increase the height of the piers. The

quantities for each such bridge therefore, for all items of work, increase proportionately with increase of height of bank above the minimum, and can be expressed as a formula

$$\text{Quantity} = pH + q \text{ cubic feet,}$$

where H is the height of formation above bed and p and q are different constants for each item of work. If r is the corresponding rate, then the cost of each item is

$$\text{Cost} = rpH + rq \text{ rupees,}$$

and the summation of all such expressions for all items of work produces a formula

$$\text{Total cost} = RH + Q \text{ rupees.}$$

For such a bridge, R and Q being known from the type quantities and selected rates, the total cost can be obtained for any required value of H . Also, it will be seen that a change of 1 foot in formation-height produces a change of cost for the bridge of R rupees.

H. *Cost of tunnels and viaducts.* — The Author has no exact data to offer concerning these. The cost of short double-line tunnels in rock, unlined, will probably not be less than 500 rupees per foot, the lining costing up to three or four times the rate for similar work in the open. As regards high bridges, two bridges with pier abutments and 60-foot girder spans, the formation being 60 to 70 feet above stream-bed, were recently estimated to cost about 500 rupees per foot of span. These figures emphasize how many times more costly tunnels and such high bridges are than ordinary earthwork as given in table II.

I. — *Cost of permanent way and ballast.* — The Central Indian Coalfields Railway project figure (1925) for 90-lb. British standard flat-footed rails, bearing-plates, and wooden sleepers, was 50 500 rupees per mile of track, including freight, labour, and the cost of main-

tenance for a year. Ballast was estimated to cost 5 500 rupees per mile of track.

J. — *Standards for gradients and vertical curves.* — Vertical curves should be allowed for when laying out the grading. Where other factors do not intervene, a balance should be kept, after the vertical curve is inserted, between the cost of earthwork, etc., and that of rise and fall, at summits and sags in the grading.

The standards used for the Central Indian Coalfields Railway project were :

For sags, a rate of change of gradient of 0.1 % per chain;

For summits, a rate of change of gradient of 0.2 % per chain.

K. — *Curvature.* — Compensation for curvature was given in grading at the rate of 0.04 % per degree of curve. This figure is equivalent to a compensation of 1 foot of height for every 25 degrees through which the line turns — a figure independent of the radius, the gradient, or the distance traversed, which is most useful to the locating engineer.

Transition-curves were based on the formulas given in the *Maximum and Minimum Standard Dimensions for Indian Railways*, 1922,

where the length $= 8 \sqrt{\text{radius in feet.}}$

and the shift, $s = \frac{L^2}{24R}$,

is a constant figure of 2 ft. 8 in.

For curves of $2\frac{1}{2}^\circ$ and flatter, this formula produces an unduly long transition, and in such cases the alternative formula, length in feet $= 6$ times the maximum permissible speed in miles per hour was used, with a limiting maximum length of 360 feet.

To provide room for such transition-curves, no curve should be less than 400 feet in length between true circular tangent points. With reverse curves, a

clear length of 100 feet of straight track was allowed between the two transition-curves.

L. — *Station-yards.* — The maximum length required between the outermost facing points for ordinary wayside crossing-stations was taken as 2 600 feet, and this length was graded at 1 in 1 000, or in exceptional cases at 1 in 600. Where a falling gradient of 1 in 200 or steeper occurred at either end, an additional length of 2 chains of the station gradient was allowed to provide for the flat grading outside the points compulsory under the Standard Dimensions.

M. — *Distance between stations.* — Crossing-station sites were provided on the Central Indian Coalfields Railway project about every $5\frac{1}{2}$ miles. It is important to preserve uniformity, so as to obtain maximum capacity for traffic, but in difficult country it is not always easy to find good sites at the correct spacing. Sites must be provided in the grading in hilly country, whether stations are immediately required or not.

S. — *Future doubling.* — With the high rates of interest on capital now current, small initial savings in capital cost rapidly accumulate over a term of years, and although it frequently pays, especially in undeveloped areas where land is cheap, to acquire land for a double line at the start, yet it is usually profitable to stake out the centre-line for a single track only, on the cheapest alignment. It is, however, often desirable to locate so that one side of the original line can be reserved for future doubling without unnecessary expense, and some thought may be taken as to the side selected. In hilly and rocky country such as was met with on much of the Central Indian Coalfields Railway, if the lower side of the line on sidelong ground is reserved for doubling, catch-water drains, nullah-diversions, etc., on

TABLE II.

Approximate costs of earthwork per chain of bank or cutting : rupees.

Data : Banks 20 feet wide on top, slopes 2 to 1.

Cuttings 24 feet wide at bottom, slopes $\frac{1}{2}$ to 1 in rock, 1 to 1 in soil. Ground assumed to have no cross slope.
 Assumed rates, per 1 000 cubic feet : rupees. Ordinary soil, 7/-; hard soil, 10/-; soft rock, 40/-; hard rock, 70/-; lead and lift, 4/- per chain and per 5-foot lift; lead for line 9, 10/-.

NATURE OF SOIL, Etc.	Height of formation : feet.									
	5	10	15	20	25	30	35	40	45	50
1. Banks in ordinary soil.	110	300	640	1 140	Soft soil not available for banks over 20 feet high.					
2. Banks in hard soil.	165	420	790	1 500	2 180	3 240	4 250	6 200	8 150	10 500
3. Cuttings 10 feet hard soil over soft rock. .	165	410	1 060	1 890	2 850	3 990	5 280	6 770	8 410	10 280
4. Cuttings 5 feet hard soil over soft rock. .	165	750	1 510	2 380	3 330	4 620	5 910	7 540	9 290	11 190
5. Cuttings in soft rock.	535	1 220	2 070	2 990	4 090	5 380	6 820	8 450	10 290	12 250
6. Cuttings 10 feet hard soil over hard rock. .	165	410	1 450	2 760	4 260	6 030	8 040	10 280	12 760	15 560
7. Cuttings 5 feet hard soil over hard rock. .	165	1 160	2 380	3 790	5 370	7 350	9 420	11 890	15 570	17 450
8. Cuttings in hard rock.	925	2 090	3 510	5 030	6 820	8 890	11 170	13 730	16 590	19 600
9. Banks led from cuttings.	150	400	750	1 200	1 750	2 400	3 150	4 000	4 950	6 000
10. Payment for lift and lead only, included in lines 4 and 7.	15	60	150	280	460	710	1 030	1 420	1 900	2 460

Lines 1 and 2 also apply approximately to the cost of cuttings up to 20 feet deep in earth.

Line 9 shows the cost of lead only, cost of excavation being reckoned against the cost of cutting.

Line 10 shows the cost of lift out of cuttings, which would be saved were the material led to bank as in line 9.

hillsides above the line need not be interfered with later. In plains country, where most of the line will be in bank and where almost every bridge will have a masonry floor with a drop wall at the downstream side, the opposite may hold good.

The question whether bridges for double line should be provided must be considered in some such way as the following :

1. What is the immediate saving of cost due to building a bridge for a single instead of for a double line ?

2. What will be the cost of doubling such a bridge later ? This can only be estimated, since future conditions are not known.

3. In how many years will saving 1. accumulated at suitable compound interest, produce amount 2. ? The period found must then be compared with the prospects of the line, and unless it seems likely that the line will require doubling within that period of years, the bridge should not ordinarily be built double in the first place.

In certain cases technical considerations may make it desirable to build for a double line at the outset; for example, a bridge on single-line well-foundations can only be doubled conveniently by the construction of a duplicate bridge, and similar considerations will often apply to foundations involving difficult wet excavation. In such cases, the additional expense of the separate approaches to the duplicate bridge, or perhaps the difficulty of fitting them in where there are sharp curves, justifies double-line piers or foundations from the start.

With suitable designs, the ratio between costs 1. and 2. above can be kept low, and for the Central Indian Coal-fields Railway project the period 3. was estimated at about 8-10 years : this was well within the probable life of the railway as a single line, and there was there-

fore no justification for double-line bridges in ordinary cases.

Work in the field.

General conditions concerning location and grading. — Table I shows the importance, once the ruling gradient has been fixed, of a direct line, especially when the traffic is likely to be heavy. For instance, with a traffic of eight trains a day in each direction, the capitalized value of curvature may be at the rate of 312 rupees per degree turned through, while small savings of length, when the value of track saved in consequence is also included, may cheapen the line on a capitalized basis at the rate of 2 lakhs rupees per mile saved.

It is repeatedly found in practice that minor diversions from and back to a direct line round a series of small natural features cost more in the capitalized value of curvature and extra length than is saved by the diversions in cost of works. Where long lengths of ruling gradient are concerned, especially with easy gradients, such diversions usually lose more height in compensation for extra curvature than they gain by the extra length brought in. Indeed, it is only by very abrupt and extensive diversions from the direct-line that any effective development to gain height can be made.

When the ruling gradient and the due provision of adequate vertical curves permit, humps and sags in the grading frequently show a considerable saving in construction-cost as compared with working-expenses. For instance, a rise of 1 foot comes under line 4 of table I, and with as many as eight trains in each direction costs about 850 rupees in capitalized working-expenses. The figures of line 7 of table II show that a 1-foot reduction of depth in a cutting entering hard rock may save 300 rupees per chain, and when possible it pays to raise formation for a long cutting accordingly.

Where small sags are concerned the capitalized cost, on Mr. Wellington's arguments, is about one-fourth of the previous figure, say 200 rupees per foot of sag with eight daily trains each way. The saving in earthworth is much less for a bank than for the cutting just considered, and would be about 100 rupees per chain for a foot saved in a 20-foot bank in ordinary soil.

As already stated, the necessity for long lengths of ruling gradient and for adequate vertical curves limits the introduction of such sags and humps in many cases where they might otherwise be put in, but the principles brought out as to the savings of construction-cost by small changes of height of formation can be used extensively in the correct siting of the alignment to produce a proper balance between the cost of cuttings and of banks and bridging.

Conduct of work. — In the hilly jungle country through which most of the work of the Author's party on these surveys had to be taken, and where a force of jungle-cutters was required to clear a line for almost every long sight taken, he found it essential to map and contour from a preliminary traverse-line the strip of ground he expected to follow. The final alignment was then fixed on the map after due comparison of possible lines by plotting their longitudinal sections from the contours, and it was transferred (to about the nearest foot) to the ground by measurements from the temporary pegs of the preliminary traverse and set out by chain and theodolite in the ordinary way. A similar procedure would often simplify location in less difficult country, because it would enable villages, wells, and other expensive areas and obstacles to be avoided with minimum length and curvature at a negligible additional cost of survey.

The preliminary traverse was run by compass and chain, temporary pegs numbered in blue pencil being put down at

every chain and station. A detailed leveler followed taking levels at every peg and at stream-beds, etc., and leaving benchmarks at intervals of about $1/4$ mile. One or more cross-sectioners followed, and marked out and levelled cross sections 200 or 300 feet apart, leaving small numbered temporary pegs at every chain on each cross section. The main traverse (calculated by latitudes and departures) and the cross sections were then plotted on plane-table sheets (22 inches by 20 inches was found to be convenient) with the levels at each peg, etc., written on them — to the nearest whole foot — as spot-levels, after which plane-tablers working with compass and hand-level completed the plans from the framework thus set out. The provision of pegs on the ground on both traverse and cross sections facilitated the plane-tablers' work in close country. Time is saved and the value of the work is much increased by doing the contouring in this way in the field rather than in the office — a procedure only suitable for quite smooth slopes and unbroken country.

When the line was being cut for the preliminary traverse it was found essential, in dealing with long lengths of ruling gradient to keep track of levels and of distances run, and this was easily done by the use of a level with stadia hairs (especially the Zeiss pattern level having a horizontal axis of adjustment to the telescope), with which fly levels and distances were read and carried forward just behind the cutting party, to enable the traverse to be kept on ground suitable for the required formation-level at any distance along the gradient. Such long lengths of ruling gradient should in most cases be dealt with from the top downwards. It is very difficult to foresee the exact point at which an ascending ruling gradient must begin, in order to reach controlling summit correctly.

Marking the located line. — Permanent points on the located line were marked

by dwarf pillars of cement concrete, with the centre line cut into the concrete while it was still soft. For this work sixteen wooden forms shaped like a truncated pyramid 8 inches high, 12 inches square at the top, and 15 inches at the base, were used.

The *Rules for the preparation of railway projects* lay down that pegs are to be left at tangent-points and apex-points, and at every thousand feet. In undulating country such points frequently occur in low ground, and it is very desirable, therefore, also to mark permanently what may be called « theodolite-points » at commanding positions on each straight, from which, with a minimum of instrument work, the construction engineers can pick up or check the setting-out of the line. A similar remark applies to curves, where the work of construction is facilitated if permanent exact marks are left (and shown on the plans) at points where the configuration of the ground made it necessary to place the instrument when first setting out the curve.

It has been the Author's practice when setting out to provide for transition-curves by shifting the circular curves inwards the correct amount, a matter simply done after calculating the tangent-lengths to be set out for a slightly increased radius of « nominal radius plus shift ».

The degree system is used for curves in India, and curves set out in this way, while preserving their true nominal radius, which makes for speed and convenience in instrument work during construction and afterwards, also have their centre-line of setting-out and of longitudinal measurement in the same constant position in relation to the track as for the straight portions of the line, thus avoiding ambiguity as to land-widths and also preventing a small cumulative difference of length on every curve, which would be liable to be a further

source of future confusion as to boundaries of land, acquired and set out from the original construction chainages.

Instruments. — The Author started these surveys with a considerable theoretical predilection for the use of a tachometer. In those days, however, he had merely an ordinary tachometer of the standard pattern available, and it was found that the reduction of the readings, even by approximate methods, took an undue amount of the time of the more highly trained members of the party. Apart from this, only short sights were usually possible in the jungle country traversed, without undue cutting of trees and branches, and in such circumstances progress was slow, while the accuracy of linear and angular measurements was in advance of the standard required for the 200-feet-to-the-inch plans being produced, with contours at 5-foot intervals. It was also found that ordinary spirit levelling was necessary in addition, unless quite undue time was spent over the tachometer, to ensure that errors in levels were not carried forward.

As a result, the tachometer, used by a comparatively highly paid man, was abandoned for chain, compass, level, and plane table, with which several less highly trained men were able to produce more work.

The Author considers that in more open country, where long sights up to 2 000 feet can be got, it would often be profitable to use the theodolite for preliminary traverse work instead of the compass, since all questions of local attraction and magnetic variation would thereby be eliminated.

In the course of the Author's later work, a Jeffcott tachometer became available, in which distances and rise or fall are read directly from the staff by means of automatically-moved needles in the place of the usual cross-hairs. The use of this instrument is easily learnt, and with it numerous spot levels

at all elevations can quickly be fixed on the plan up to distances of 600 or 800 feet from the instrument. In open or barren country its value should be very great indeed, especially as the same instrument can be used without difficulty for all the ordinary setting-out work usually done by theodolite. In jungle its use for traverse work is hampered by the need for extensive cutting. The

Author's instrument, however, proved itself invaluable in cross-sectioning work on steep hillsides, where, from a single set-up, 600 feet or more of cross section, covering perhaps more than 100 feet of vertical height, could be taken with a speed and accuracy not approached by any other means; and it is an instrument which no party working in difficult country should be without.

APPENDIX.

Estimated increase of working-cost due to increase of ruling gradient from 1 in 200 to 1 in 100.

First consider cases in which the length of line is not materially affected by the change in gradient. Making the assumption that engines weighing 110 tons, which can regularly handle loads of 1 650 tons behind the tender on 1-in-200 gradients, are to be used, let L denote their load in tons for a 1-in-100 gradient, then

$$(110 + L) \text{ tons} \times (6 + 22.4) \text{ lb. must} \\ = 30\,270 \text{ lb.}$$

the last figure being that deduced on p. 792. This equation gives $L = 960$ tons; that is to say, the train-mileage to carry a given traffic over the steeper gradient must be increased in the proportion of 1 650 : 960, or by about 72 % (1).

The additional train-mileage costs less

than the initial mileage, and to make an estimate of its probable cost a conservative figure for the purpose of this calculation is obtained by eliminating items (i), (k), and (l), and half of item (j) from column 5 of table III. The resulting total is 19.76 annas (1.23 rupees), equivalent to about 30 % of the original cost per train-mile.

If for every original daily train, 0.72 train is required in addition, for the steeper gradient, as shown above, the annual cost per daily train in each direction per mile of line is — 2 trains (up and down) \times 365 days \times 0.72 \times 1.23 rupees = 645 rupees.

Such an annual cost, with interest at 5 %, represents a capital outlay of 12 900 rupees, and it will not pay to steepen the gradient accordingly, unless the construction-cost can be cheapened in consequence by 12 900 rupees per mile over the whole engine-run, per original daily train in each direction. Such a saving can be made (apart from any savings of distance), only on formation and bridging, and it is obvious that where the number of daily trains exceeds two or

(1) The figure 30 270 lb. was obtained by the use of a figure of 6 lb. per ton for train-resistance on the level. Had this figure been taken at 7 lb. the above percentage on a similar calculation would have been 69 %, while a figure of 8 lb. per ton would make it 65 %. The exact figure taken does not, therefore, very greatly affect this result.

TABLE III.

Summary of the estimated effect of changes of distance, curvature, and rise and fall on the cost of working a single train daily in each direction.

HEADS OF WORKING EXPENSES.	For short increases in ke		For larger increases take		For larger increases involving stations take		For 600' of curvature take		For 25.4 feet rise and fall class B take		For 25.4 feet rise and fall class C take	
	1	2	3	4	5	6	7	8	9	10	11	12
	Annas.	Annas.	Per cent.	Annas.	Annas.	Per cent.	Annas.	Per cent.	Annas.	Per cent.	Annas.	Per cent.
a) Fuel	2.50	1.67	67	1.67	85	2.12	50	1.25	33	0.83	100	2.50
b) Water	0.30	0.15	25	0.07	50	0.15	25	0.07	20	0.06	50	0.15
c) Oil and waste	0.30	0.15	50	0.15	50	0.15	25	0.07	20	0.06	50	0.15
d) Engine repairs	4.28	4.0	40	1.71	57	2.44	125	5.35	1	0.04	4	0.17
e) Switching engines	3.54	4	4	0.44	5	0.18	5	0.18	1	0.04	4	0.14
f) Train wages and supplies	4.68	43	2.00	43	2.00	43	2.00	43	2.00	43	2.00	43
g) Car repairs	9.00	35	3.15	35	3.15	50	4.50	120	1	0.09	4	0.36
h) Car mileage	1.53	400	1.53	400	1.53	400	1.53	400	1.53	400	1.53	400
i) Rail renewals	1.55	80	1.24	100	1.55	100	1.55	300	5	0.08	10	0.16
j) Adjusting track	2.21	50	4.11	100	2.21	100	2.21	50	4.11	100	5	0.11
k) Sleeper renewals	4.39	100	4.39	100	4.39	100	4.39	50	2.19	100	5	0.22
l) Earthwork and ballast	0.41	100	0.41	100	0.41	100	0.41	50	0.21	100	5	0.02
m) Yards and structures	2.28	10	0.23	50	1.14	50	1.14	50	1.14	50	5	0.02
n) Station and general	27.34	7 1/2	2.08	7 1/2	2.08	16	4.44	40	25.88	1.20	3.98	100
Totals	64.31	30	19.48	33	21.29	42	27.21	40	25.88	1.20	3.98	100

Addition to columns 7 and 8 of 3% of column 2 to provide for rise and fall on ruling gradients 1.92

Final figures.

Capitalized effects of the above.

	3	4	5	6	7	8
	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.
Annual cost for one train daily in each direction	mile 890	mile 970	mile 1 240	600° 1 180	26.4 feet 142	26.4 feet 275
Ditto capitalized at 5%	mile 17 800	mile 19 400	mile 24 800	600° 23 600	26.4 feet 2 840	26.4 feet 5 500
Capital value	foot 3.4	mile 19 400	mile 24 880	degree 39	foot 107	foot 210

Note. — The figures given here for rise and fall are for such on ruling gradients. These figures are much increased in comparison with the cost of rise and fall on gradients lighter than the ruling gradient.

three, savings of this order will not be possible.

This calculation does not include the cost of the additional locomotives required, namely, 2×0.72 additional locomotives, for each daily train each way. On the basis of locomotives costing 1 lakh rupees each, this would amount to 144 000 rupees or about 1 440 rupees per mile over an engine-run of 100 miles, per original daily train each way. In practice this sum would be increased by the elimination of fractions of a locomotive and by the necessary provision of additional spare engines.

Now consider cases in which the adoption of a modified route with a steeper gradient permits of savings of distance. Assume a line 100 miles long, costing, without rolling stock, 2 lakhs rupees per mile, and assume that this is reduced to 90 miles in length by the use of the steeper gradient.

Then the annual cost of additional train-mileage due to the increased number of trains required will be

$$90 \times 2 \times 365 \times 0.72 \times 1.23 \text{ rupees} = 58\,100 \text{ rupees}$$

per original daily train.

Less an annual saving due to 10 miles shorter distance, of

$$10 \times 2 \times 365 \times 1.70 \text{ rupees } ^{(1)} = 12\,400 \text{ rupees}$$

per original daily train.

The net increase of 45 700 rupees capitalizes at 914 000 rupees per daily train, to which must be added 144 000

rupees for the cost of the additional locomotives required, making a grand total of about 1 058 000 rupees per original daily train in each direction.

The assumed saving of construction cost due merely to a reduction of 10 miles in length is 2 000 000 rupees in all, so that with more than two daily trains in each direction a considerable further saving in construction cost due to the adoption of the steeper route will be necessary before the latter proves profitable.

A similar calculation, assuming a reduction to 80 miles in length by the use of the steeper gradient, gives an increased working cost for the latter capitalizing at 682 000 rupees per original daily train, against an assumed saving of construction cost, due merely to the 20 miles reduction in length, of 4 000 000 rupees. With eight daily trains each way, therefore, the shorter route, in spite of its savings in length, still needs to save a further sum of about 1 450 000 rupees owing to its different alignment, on its length of 80 miles, before it becomes profitable to introduce the steep gradient.

These examples do not make any allowance for passenger-trains, where, although no extra train-mileage would probably be necessary as a result of the introduction of a steeper gradient, yet some additional expenditure per original train-mile would probably be required to provide for working the same train over a heavier line; and the figures given well illustrate the sacrifices of length and of construction cost which may profitably be made to obtain a low ruling gradient, where freight traffic of any degree of intensity is likely.

(1) Column 5 of table III.

Tunnel atmosphere tests on Chesapeake and Ohio Railroad. ⁽¹⁾

(*Railway Age.*)

At the request of the Chesapeake & Ohio Railroad a number of tests were made to determine the temperature, humidity, and composition of the atmosphere in certain tunnels of that railroad between Clifton Forge, Va., and Hinton, W. Va. The purpose of these tests was to determine conditions in the cabs of freight locomotives while pulling trains through these tunnels.

Tests were made of two types of locomotives, classified by the railroad company as the H-6 and H-7. Both are of the articulated type, but the H-6 class is of the *Mallet* compound type whereas the H-7 operates all four cylinders at boiler pressure, thereby exhausting steam at a higher temperature than the H-6. It was desired to determine the relation between conditions on the H-6 and H-7 engines under comparable conditions of operation. This information supplements previous tests by the Bureau of Mines, discussed in its Reports of Investigations Serial No. 2624 ⁽²⁾, entitled, « Temperatures in cabs of freight locomotives passing through tunnels of Chesapeake & Ohio Railroad », by S. H. Katz and E. G.

Meiter, July 1924. Three incidental tests of passenger engines were also made.

Description of tunnels.

Tests were conducted in the following tunnels: Lewis, Alleghany, Second Creek, Big Bend, and Little Bend. Particular attention was paid to the Big Bend, Second Creek, and Alleghany tunnels, as these are the longest on this subdivision and grades are encountered in all three. East-bound freight trains are « fanned » by a ventilating fan at the west end of Big Bend tunnel. Trains are kept behind the smoke when traveling east-bound in this tunnel; for this reason, tests were made of west-bound trains only. The Big Bend tunnel has an ascending grade from each end, with a high point or hump about 1500 feet from the eastern portal. The Second Creek and Alleghany tunnels have an ascending grade from west to east, and tests were made of trains traveling in this direction. Table I gives details of these tunnels.

The load pulled in all tests was at least the average tonnage for the locomotives used, and in some instances exceeded the previous maximum load pulled. In the majority of tests the trains were brought to a stop before entering tunnels. Although this is not a common practice during normal train operation, it was done on the test trains to obtain more severe conditions than usual.

Temperature measurements were taken in the tunnels with a wet and dry bulb thermometer of the sling type, and samples of the atmosphere were obtained for determination of the carbon monoxide, sulphur dioxide, carbon dioxide,

⁽¹⁾ A summary of the U. S. Bureau of Mines reports of investigations, serial No. 2858, entitled, « Tests of atmospheres in Chesapeake & Ohio Railroad Tunnels between Clifton Forge, Va., and Hinton, W. Va., » by R. R. Sayers, L. B. Berger and W. P. Yant. The authors are, respectively, chief surgeon, U. S. Bureau of Mines, and surgeon, U. S. Public Health Service; laboratory assistant, Health Laboratory Section, Pittsburgh Experiment Station, U. S. Bureau of Mines, Pittsburgh, Pa.; and supervising chemist, Health Laboratory Section, Pittsburgh Experiment Station.

⁽²⁾ See the *Railway Age* for 13 September, 1924, page 461, for an abstract of this report.

and oxygen. These temperature measurements and gas samples were taken in the engine cab near the engineman or fireman. Several qualitative tests for hydrogen sulphide were made, but all were negative. On several occasions, blood samples were taken from one of the members of the test crew as soon as possible after emerging from the tunnels. None of these samples showed any significant degree of saturation with carbon monoxide.

Big Bend tunnel tests.

Six test trips were made through the Big Bend tunnel, the first of which was operated eastbound with the tunnel fan blowing and the locomotive traveling in

fresh air behind the smoke. The effective cab temperature on this trip was 85° F. Four westbound trips were made with the simple articulated type locomotives, with trains varying in tonnage from 2 234 to 2 483 and one westbound trip was made with the *Mallet* compound locomotive and a train of 1 558 tons. The time in the tunnel on the westbound trips varied from four to five minutes. On the first westbound trip with the simple locomotive, steam was on full for two-thirds of the way through before the throttle opening was reduced. A thermometer about 18 inches from the roof and in the center of the cab, showed 140°, as the train left the tunnel and conditions were otherwise bad on this trip.

TABLE I.

Tunnels on the Alleghany Sub-Division of the Chesapeake and Ohio
in which tests were made.

NAME OF TUNNEL.	Length, feet.	Height rail to crown, feet (approx.)	Width, (feet approx.)	Grade, feet per mile.	Direction of ascending grade.	Number of tracks.	Remarks.
Little Bend	668	21 3/4	27	21	East	2	No fan in this tunnel.
Big Bend	6 501	18	14	4 21	West East	1	Four feet per mile west for about 1 500 feet at east end and 21 feet per mile east for about 2 979 feet at west end. Fan at west end blows west to east.
Second Creek. . .	1 561	18 3/4	14 1/2	20	East	1	No fan in this tunnel.
Alleghany.	4 731	19 1/2	26	30	East	2	No fan in this tunnel.
Lewis.	4 023	16	14 1/2	60	West	1	Fan at east end blows east to west on west-bound freight trains. East-bound trains drift through.

The backs of the hands of one of the observers were severely blistered. Eye, nose and throat irritation was suffered and respiration was difficult. A marked improvement in conditions was noted immediately after the throttle opening was reduced. The effective temperature

in the cab during this trip was approximately 123° F., with a relative humidity of 90 % or more. In all tests in the Big Bend tunnel except the one already mentioned, the amount of carbon monoxide was negligible as affecting health and safety. In that test one sample showed

0.06 %. This concentration would have no bad effects unless inhaled for at least one hour, and may be disregarded because exposure during passage through the tunnel is brief. There would be danger from this gas only if a train was stopped in the tunnel; then the carbon monoxide might markedly exceed the figure given.

Sulphur dioxide was present in all tests made in this tunnel, the maximum concentration found being 20 parts per million. Although this amount could not be considered dangerous, the irritating properties and odor of sulphur dioxide are decidedly unpleasant. Breathing through wet cotton waste gave relief from this gas.

As would be expected, the carbon dioxide content of the atmosphere was increased and the oxygen depleted, but conditions were never deleterious or dangerous. The maximum carbon dioxide found was 2.14 %, and the lowest oxygen 18.51 %.

On the three succeeding tests through the Big Bend tunnel with the simple articulated locomotives pulling slightly greater loads than on the first trip, conditions did not approach the unbearable degree attained on the first test. The fact that a light throttle and the tunnel ventilating fan were used probably account for the improvement in conditions.

The single test *Mallet* compound locomotive through this tunnel indicated that temperature and humidity conditions were somewhat less severe than the average for the simple engines.

On only one of six trips through the Second Creek tunnel was carbon monoxide found to an extent (0.09 %) which might be considered dangerous after exposure of 45 minutes to one hour. Sulphur dioxide was not found in dangerous amounts, the highest concentration being 20 parts per million. The increase in carbon dioxide and depletion of oxygen was not sufficient to be deleterious. The maximum carbon

dioxide found was 1.15 % and the lowest oxygen 19.73 %. On the first trip through this tunnel, much discomfort was experienced from heat and humidity. However, on the next test the same engine was used with a slightly greater load and no marked discomfort ensued. This test was made using a light throttle through the tunnel.

Temperature and humidity conditions were found to be less severe with the H-6 (compound) locomotive than with the H-7 (simple) types through this tunnel, both on trains pulled by a single engine and on trains using an engine on each end. The effective cab temperatures for the former ranged from 101° F., to 103° F., while for the latter the range was from 111° F., to approximately 123° F. The time in the tunnel varied from 1 minute 10 seconds to 3 1/2 minutes.

In tests through the Alleghany tunnel the carbon monoxide content did not reach an amount that would be unsafe or produce discomfort for an exposure of one hour. Sulphur dioxide was not present in large enough quantities to be objectionable, the maximum concentration found being five parts per million. The increase in carbon dioxide and the oxygen depletion did not reach hazardous degrees. The maximum carbon dioxide found was 1.14 % and the lowest oxygen 19.68 %.

The temperature and humidity caused no marked discomfort during the majority of trips. In the last test, where two H-7 locomotives were used, the temperature and humidity were higher than in any other test through this tunnel and were uncomfortable, but conditions did not reach an unbearable degree of severity during the time consumed in making this trip. The fact that the Alleghany tunnel is double-tracked may contribute to the better conditions found. Temperature and humidity conditions were somewhat less severe for the H-6 engines than on the H-7 type. The time in the tunnel varied from 4 1/2 to 12 minutes,

and was 9 minutes on the last test.

Tests through the Little Bend tunnel were of such short duration that samples of the atmosphere were not taken. The temperature and humidity did not cause discomfort.

During tests of passenger engines no discomfort was experienced from temperature and humidity. One test for carbon monoxide was made with an engine pulling an unusually long train. The carbon monoxide content of the atmosphere was found to be negligible from a health and safety standpoint.

General discussion of results.

Of all the tests only two showed any appreciable amount of carbon monoxide,

and this in amounts that would have no dangerous effects unless exposure was for 45 minutes or longer. There was no health hazard from sulphur dioxide, carbon dioxide, or depletion of oxygen content of the atmosphere for the time of exposure in these tests. There would be danger from the gases found only if a train was stopped while in a tunnel.

The chief cause of discomfort was the high temperature and humidity. In one test the temperature was high enough to cause a surface burn. A similar test, with the engine worked under a lighter throttle, gave conditions that caused no marked discomfort, showing the relation that train manipulation bears to the conditions in the tunnels.

TABLE II.

Effective temperatures.

TUNNEL.	H-6 engines.		H-7 engines.		Direction of travel.
	Load, tons.	Effective temperature.	Load, tons.	Effective temperature.	
Big Bend	1 558	106	4 996	85 (a)	East
			2 234	123 (approx.)	
			2 428	123	
			2 483	104	West
			2 386	123 (approx.)	
			4 996	123 (approx.)	
Second Creek	3 572 7 145 7 036	101 102 103	5 023	123 (approx.)	East
			7 145	119 (b)	
			7 036	115 (c)	
			8 191	111 (a)	
				115 (d)	
			3 945	102	
Alleghany.	2 925 7 145 7 036	89 91 100	4 195	98	East
			7 145	107 (b)	
			7 036	103 (c)	
			8 191	123 (approx.) (d)	
				98 (d)	

(a) Tunnel-ventilating fan on; engine traveling in fresh air behind smoke.
 (b) H-6 head end. H-7 rear end.
 (c) H-7 head end. H-6 rear end.
 (d) H-7 head end. H-7 rear end.

Although many of the effective temperatures given are above those that would be practicable for long exposure, men are able to work for short periods — 10 to 15 minutes — in temperatures up to 135° F. with 100 % relative humidity without marked inconvenience; an exposure of one hour is not practicable. An exposure of one hour to 98° F. with 100 % relative humidity causes the pulse-rate to be greatly increased, as well as causing a marked increase in body temperature and body metabolism, even when the individual remains at rest.

The maximum endurance found at

105° F. saturated air is approximately 45 minutes and at 117° F. the limit of endurance is 15 minutes; 135° F. effective temperature could not be borne for any length of time by a man with a skin directly exposed. Thick clothing will protect or, in other words, will insulate the body from such temperatures. Work has been performed at 135° F. effective temperature by using special suits of thick felt. Under these circumstances work has been performed for 15 to 20 minutes. It is noted that because of this clothing insulation the unclothed body is not actually exposed to the temperatures.